HALF HOUR RECREATIONS

INTER FOLIA FRUCTUS

IN POPULAR SCIENCE.

HALF-HOUR RECREATIONS

IN

POPULAR SCIENCE.

FIRST SERIES.

BY

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HALF HOUR RECREATIONS

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1. Strange Discoveries respecting the Aurora.

ONE of the most mysterious and beautiful of Nature's manifestations promises soon to disclose its secret. The brilliant streamers of colored light which wave at certain seasons over the heavens have long since been recognized as among the most singular and impressive of all the phenomena which the skies present to our view. There is something surpassingly beautiful in the appearance of the true "auroral curtain." Fringed with colored streamers, it waves to and fro as though shaken by some unseen hand. Then from end to end there pass a succession of undulations, the folds of the curtain interwrapping and forming a series of graceful curves. Suddenly, and as by magic, there succeeds a perfect stillness, as though the unseen power which had been displaying the varied beauties of the auroral curtain were resting for a moment. But even while the motion of the curtain is stilled, we see its light mysteriously waxing and waning. Then, as we gaze, fresh waves of disturbance traverse the magic canopy. Startling coruscations add splendor to the scene, while the noble span of the auroral arch from which the waving curtain seems to depend, gives a grandeur to the spectacle which no words can adequately describe. Gradually, however, the celestial fires which have illuminated the gorgeous arch seem to die out. The luminous zone breaks up. The scene of the display

becomes covered with scattered streaks and patches of ashen gray light, which hang like clouds over the northern heavens. Then these in turn disappear, and nothing remains of the brilliant spectacle but a dark smoke-like segment on the horizon.

Such is the aurora as seen in arctic or antarctic regions, where the phenomenon appears in its fullest beauty. Even in our own latitudes, however, strikingly beautiful auroral displays may sometimes be witnessed. Yet those who have seen the spectacle presented near the true home of the aurora, recognize in other auroras a want of the fulness and splendor of color which form the most striking features of the arctic and antarctic auroral curtains.

Hitherto the nature of the aurora has been a mystery to men of science; nor, indeed, does the discovery we are about to describe throw even now full light on the character of the phenomenon. That discovery, however, affords promise of a speedy solution of the perplexing problems presented by auroral displays; and in itself it is so full of interest and so suggestive, that our physicists already recognize it as one of the most important which have been made in recent times.

A few brief words, in explanation of the progress which had been effected in the study of auroral phenomena, will serve to render the interest and importance of the discovery we have to describe more apparent.

Let it be premised, then, that physicists had long since recognized in the aurora a phenomenon of more than local, of more even than terrestrial, significance. They had learned to associate it with relations which affect the whole planetary scheme. Let us inquire how this had come about.

So long as men merely studied the appearances presented by the aurora, so long, in fact, as they merely regarded the phenomena as a local display, they could form no adequate conception of its importance. The circumstance which first

revealed something of the true character of the aurora was one which seemed to promise little.

Arago was engaged in watching from day to day, and from year to year, the vibrations of the magnetic needle in the Paris Observatory. He traced the slow progress of the needle to its extreme westerly variation, and watched its course as it began to retrace its way towards the true north. He discovered the minute vibration which the needle makes each day across its mean position. He noticed that this vibration is variable in extent; and so he was led to watch it more closely. Thus he had occasion to observe more attentively than had yet been done the sudden irregularities which occasionally characterize the daily movements of the needle.

All this seems to have nothing to do with the auroral streamers; but we now reach the important discovery which rewarded Arago's patient watchfulness.

In January, 1819, he published a statement to the effect that the sudden changes of the magnetic needle are often associated with the occurrence of an aurora. I give the statement in his own words, as translated by General Sabine: "Auroras ought to be placed in the first rank among the causes which sometimes disturb the regular march of the diurnal changes of the magnetic needle. These do not, even in summer, exceed a quarter of a degree, but when an aurora appears, the magnetic needle is often seen to move in a few instants over several degrees." "During an aurora," he adds, "one often sees in the northern region of the heavens luminous streamers of different colors shoot from all points of the horizon. The point in the sky to which these streamers converge is precisely the point to which a magnetized needle suspended by its centre of gravity directs itself. . . . It has, moreover, been shown that the concentric circular segments, almost similar in form to the rainbow, which are usually seen previous to the appearance of the luminous streamers, have their two

extremities resting on two parts of the horizon which are equally distant from the direction towards which the needle turns; and the summit of each arc lies exactly in that direction. *From all this it appears, incontestably, that there is an intimate connection between the causes of auroras and those of terrestrial magnetism.*"

This strange hypothesis was, at first, much opposed by scientific men. Amongst others the late Sir David Brewster pointed out a variety of objections, some of which appeared at first sight of great force. Thus, he remarked that magnetic disturbances of the most remarkable character have often been observed when no aurora has been visible; and he noticed certain peculiarities in the auroras observed near the polar regions, which did not seem to accord with Arago's view.

But gradually it was found that physicists had mistaken the character of the auroral display. It appeared that the magnetic needle not only swayed responsively to auroras observable in the immediate neighborhood, but to auroras in progress hundreds or even thousands of miles away. Nay, as inquiry progressed, it was discovered that the needles in our northern observatories are swayed by influences associated even with the occurrence of auroras around the southern polar regions.

In fact, not only have the difficulties pointed out (very properly, it need hardly be remarked) by Sir David Brewster been wholly removed, but it has been found that a much closer bond of sympathy exists between the magnetized needle and the auroral streamers than even Arago had supposed. It is not merely the case that while an auroral display is in progress the needle is subject to unusual disturbance, but the movements of the needle are actually synchronous with the waving movements of the mysterious streamers. An aurora may be in progress in the north of Europe, or even in Asia or America, and as the colored banners wave to and fro, the tiny needle, watched by patient

observers at Greenwich or Paris, will respond to every phase of the display.

And I may notice in passing that two very interesting conclusions follow from this peculiarity. First, every magnetic needle over the whole earth must be simultaneously disturbed; and secondly, the auroral streamers which wave across the skies of one country must move synchronously with those which are visible in the skies of another country, even though thousands of miles may separate the two regions.

But I must pass on to consider further the circumstances which give interest and significance to the strange discovery which is the subject of this paper.

Could we only associate auroras with terrestrial magnetism, we should still have done much to enhance the interest which the beautiful phenomenon is calculated to excite. But when once this association has been established, others of even greater interest are brought into recognition. For terrestrial magnetism has been clearly shown to be influenced directly by the action of the sun. The needle in its daily vibration follows the sun, not indeed through a complete revolution, but as far as the influence of other forces will permit. This has been abundantly confirmed, and is a fact of extreme importance in the theory of terrestrial magnetism. Wherever the sun may be, either on the visible heavens or on that half of the celestial sphere which is at the moment beneath the horizon, the end of the needle nearest to the sun makes an effort (so to speak) to point more directly towards the great ruling centre of the planetary scheme. Seeing, then, that the daily vibration of the needle is thus caused, we recognize the fact that the disturbances of the daily vibration may be referred to some peculiarity of the solar action.

It was not, therefore, so surprising as many have supposed, that the increase and diminution of these disturbances, in a period of about eleven years, should be found to

correspond with the increase and diminution of the number of solar spots in a period of equal length.

We already begin to see, then, that auroras are associated in some mysterious way with the action of the solar rays. The phenomenon which had been looked on for so many ages as a mere spectacle, caused perhaps by some process in the upper regions of the air, of a simply local character, has been brought into the range of planetary phenomena. As surely as the brilliant planets which deck the nocturnal skies are illuminated by the same orb which gives us our days and seasons, so are they subject to the same mysterious influence which causes the northern banners to wave resplendently over the star-lit depths of heaven. Nay, it is even probable that every flicker and coruscation of our auroral displays corresponds with similar manifestations upon every planet which travels round the sun. It becomes, then, a question of exceeding interest to inquire what is the nature of the mysterious apparition which from time to time illuminates our skies. We have learned something of the laws according to which the aurora appears; but what is its true nature? What sort of light is that which illuminates the heavens? Is there some process of combustion going on in the upper regions of our atmosphere? Or are the auroral streamers electric or phosphorescent? Or, lastly, is the light simply solar light reflected from some substance which exists at an enormous elevation above the earth?

All these views have from time to time found supporters among scientific men. It need hardly be said that what we now know of the association between auroral action and some form of solar disturbance, would at once enable us to reject some of these hypotheses. But we need not discuss the subject from this point of view; because a mode of research has recently been rendered available which at once answers our inquiries as to the general character of any kind of light. I proceed to consider the application of this method to the light from the auroral streamers.

The spectroscope, or, as we may term the instrument, the "light-sifter," tells us of what nature an object which is a source of light may be. If the object is a luminous solid or liquid, the instrument converts its light into a rainbow-colored streak. If the object is a luminous vapor, its light is converted into a few bright lines. And, lastly, if the object is a luminous solid or liquid shining through any vapors, the rainbow-colored streak again makes its appearance, but it is now crossed by dark lines, corresponding to the vapors which surround the object aud absorb a portion of its light.

But I must not omit to notice two circumstances which render the interpretation of a spectrum somewhat less simple than it would otherwise be.

In the first place, if an object is shining by reflected light its spectrum is precisely similar to that of the object whose light illuminates it. Thus we cannot pronounce positively as to the nature of an object merely from the appearance of its spectrum, unless we are quite certain that the object is self-luminous. For example, we observe the solar spectrum to be a rainbow-colored streak crossed by a multitude of dark lines, and we conclude accordingly that the sun is an incandescent globe shining through a complex vaporous atmosphere. We feel no doubt on this point, because we are absolutely certain that the sun is self-luminous. Again, we observe the spectrum of the moon to be exactly similar to the solar spectrum, only, of course, much less brilliant. And here also we feel no doubt in interpreting the result. We know, certainly, that the moon is not self-luminous, and therefore we conclude with the utmost certainty that the light we receive from her is simply reflected solar light. So far all is clear. But now take the case of an object like a comet, which may or may not be self-luminous. If we find that a comet's spectrum resembles the sun's, — and this is not altogether a hypothetical case, for a portion of the light of every comet yet examined does in reality give a rainbow-

colored streak resembling the solar spectrum, — we cannot form, in that case, any such positive conclusion. The comet may be a self-luminous body, but, on the other hand, its light may be due merely to the reflection of the solar beams. Accordingly, we find that our spectroscopists always accompany the record of such an observation with an expression of doubt as to the real nature of the object which is the source of light.

Secondly, when an electric spark flashes through any vapor, its light gives a spectrum which indicates the nature, not only of the vapor through which the spark has passed, but of the substances between which the spark has travelled. Thus, if we cause an electric flash to pass between iron points through common air, we see in the spectrum the numerous bright lines which form the spectrum of iron, and in addition we see the bright lines belonging to the gases which form our atmosphere.

Both the considerations above discussed are of the utmost importance in studying the subject of the auroral light as analyzed by the spectroscope, because there are many difficulties in forming a general opinion as to the nature of the auroral light, while there are circumstances which would lead us to anticipate that the light is electric.

We notice also in passing that we owe to the German physicist Angström a large share of the researches on which the above results respecting the spectrum of the electric spark are founded. The reader will presently see why we have brought Angström's name prominently forward in connection with the interesting branch of spectroscopic analysis just referred to. If the discovery we are approaching had been effected by a tyro in the use of the spectroscope, doubts might very reasonably have been entertained respecting the exactness of the observations on which the discovery rests.

It was suggested many years ago, long indeed before the true powers of the spectroscopic analysis had been revealed,

that perhaps if the light of the aurora were analyzed by the prism, evidence could be obtained of its electric nature. The eminent meteorologist Dové remarked, for instance, that "the peculiarities presented by the electric light are so marked that it appears easy to decide definitely by prismatic analysis, whether the light of the aurora is or is not electric." Singularly enough, however, the first proof that the auroral light is of an electric nature was derived from a very different mode of inquiry. Dr. Robinson, of Armagh, discovered in 1858 (a year before Kirchhoff's recognition of the powers of spectroscopic analysis) that the light of the aurora possesses in a peculiar degree a property termed fluorescence, which is a recognized and characteristic property of the light produced by electrical discharges. "These effects," he remarks of the appearances presented by the auroral light under the tests he applied, "were so strong in relation to the actual intensity of the light, that they appear to afford an additional evidence of the electric origin of the phenomenon."

Passing over this ingenious application of one of the most singular and interesting properties of light, we find that the earliest determination of the real nature of the auroral light — or rather of its spectrum — was that effected by Angström. This observer took advantage of the occurrence of a brilliant aurora in the winter of 1867–68 to analyze the spectrum of the colored streamers. *A single bright line only was seen!* Otto Struve, an eminent Russian astronomer, shortly afterwards made confirmatory observations. At the meeting of the Royal Astronomical Society in June, 1868, Mr. Huggins, F. R. S., thus described Struve's results: "In a letter, M. Otto Struve has informed me that he has had two good opportunities of observing the spectrum of the aurora borealis. The spectrum consists of one line, and the light is therefore monochromatic. The line falls near the margin of the yellow and green portions of the spectrum. . . . This shows that the monochromatic light is

greenish, which surprised me; but General Sabine tells me that in his polar expeditions he has frequently seen the aurora tinged with green, and this appearance corresponds with the position of the line seen by M. Struve."

The general import of this observation there is no mistaking. It teaches us that the light of the aurora is due to luminous vapor, and we may conclude, with every appearance of probability, that the luminosity of the vapor is due to the passage of electric discharges through it. It is, however, possible that the position of the bright line may be due to the character of the particles between which the discharge takes place.

But the view we are to take must depend upon the position of the line. Here a difficulty presents itself. There is no known terrestrial element whose spectrum has a bright line precisely in the position of the line in the auroral spectrum. And mere proximity has no significance whatever in spectroscopic analysis. Two elements differing as much from each other in character as iron and hydrogen may have lines so closely approximating in position that only the most powerful spectroscope can indicate the difference. So that when Angström remarks that the bright line he has seen lies slightly to the left of a well-known group of lines belonging to the metal calcium (the principal ingredient of common chalk), we are by no means to infer that he supposes the substance which causes the presence of the bright line has any resemblance to that element. Until we can find an element which has a bright line in its spectrum absolutely coincident with the bright line detected by Angström in the spectrum of the aurora,* all speculation as to the real nature of the vapor in which the auroral electric discharge takes place, or of the substance between which the spark travels, is altogether precluded.

* Other green lines have since been discovered in the auroral spectrum; and occasionally a red line is seen.

But interesting as the discovery undoubtedly is, we have now to deal with one of a yet more interesting character.

Most of my readers have doubtless heard of the zodiacal light, and many of them have perhaps seen that mysterious radiance, pointing obliquely upwards from the western horizon soon after sunset in the spring months, or in autumn shortly before sunrise, above the eastern horizon. The light, as its name indeed implies, lies upon that region of the heavens along which the planets travel. Accordingly, astronomers have associated it with the planetary orbits, and have come to look on it as formed by the light reflected from a multitude of minute bodies travelling around the sun within the orbit of our earth.

Yet it had long been recognized that there are difficulties in the way of this theory. Passing over those which depend on the position of the zodiacal light upon the heavens, there are difficulties connected with the appearance of the object. For example, its light has often been observed to flicker or coruscate in a manner which it seemed difficult to ascribe to the motions of our own atmosphere. Then again there have been seasons when the zodiacal light has shone with unusual intensity for months together, and there is nothing in the received theory which can account for such a peculiarity. Lastly, there is a strange circumstance recorded by Baron Humboldt that the zodiacal light is often invisible when night first sets in, and then suddenly appears with full splendor; a phenomenon which is utterly inexplicable if the received theory be accepted. The whole account of the phenomenon, as given by Baron Humboldt, is so interesting, and for my present purpose so significant, that I give it at full length: —

"In the tropical climate of South America," he remarks, "the variable strength of the light of the zodiacal gleam struck me at times with utter amazement. As I there passed the beautiful nights, in the open air, on the banks of rivers, and in the grassy plains, for several months together, I had

opportunities of observing the phenomenon with attention. When the zodiacal light was at its very brightest, it sometimes happened that but a few minutes afterwards it became notably weakened, and then it suddenly gleamed up again with its former brilliancy. In particular instances, I believed that I remarked — not anything of a ruddy tinge, or an interior arched obscuration, or an emission of sparks, such as Mairan describes, but — a kind of unsteadiness and flickering of the light."

Despite these and similar observations, very little doubt had been felt by astronomers that the zodiacal light really indicates the presence of minute bodies travelling in more or less eccentric paths round the sun. And it was confidently expected that whenever a spectroscope of sufficient delicacy to analyze the faint light of the zodiacal gleam was applied to that purpose, the resulting spectrum would be merely a very faint reproduction of the solar spectrum.

Recently, however, the zodiacal light has been analyzed by Angström, with a result altogether unexpected, and at present almost unintelligible. *Its spectrum exhibits a bright line, and this bright line is the same that is seen in the spectrum of the aurora borealis!*

How are we to understand this most surprising result? Remembering that the aurora is undoubtedly a terrestrial light, whencesoever it derives its luminosity, — in other words, that the electric discharges, however excited, really take place in the upper regions of our own atmosphere, while as certainly the zodiacal light is an extra-terrestrial phenomenon, — the observed phenomenon becomes one of the most perplexing discoveries ever made by man. That it will before long be interpreted we have no doubt whatever; nor do we doubt that the interpretation will involve the explanation of a whole series of phenomena which have lately perplexed astronomers. Recalling the association between auroras and terrestrial magnetism, and that between terrestrial magnetism and the solar spots, and remem-

bering further that our physicists have recently detected well-marked signs that the planets in their courses influence the sun's atmosphere and generate his spots in some manner yet unexplained, we see that the one fact wanting to explain Angström's discovery is undoubtedly not an isolated fact, but must be associated in the most intimate manner with a variety of important cosmical relations. To speculate as to the nature of the as yet undiscovered interpretation of Angström's researches, would at present be an idle task, perhaps. But one feature of the solar scheme with which we cannot doubt that it will be found to be associated, must be mentioned before we conclude.

Of all the phenomena presented to the contemplation of astronomers, the tails of comets are undoubtedly the most perplexing. Their rapid formation, their swift motions (if indeed we could believe that their changes of position are due to a real transmission of their material substance), and the enormous variety of configuration and of structure which they present to our contemplation, render them not merely amazing, but altogether unintelligible.

Now, there is one feature of comets' tails which has long since attracted attention, and will remind the reader of the peculiarities common to the zodiacal and the auroral light. We refer to the sudden changes of brilliancy, the flickerings or coruscations, and the instantaneous lengthening and shortening of these mysterious appendages. Olbers spoke of "explosions and pulsations which in a few seconds went trembling through the whole length of a comet's tail, with the effect now of lengthening, now of abridging it by several degrees." And the eminent mathematician Euler was led by the observation of similar appearances to put forward the theory "*that there is a great affinity between these tails, the zodiacal light, and the aurora borealis.*" The late Admiral Smyth, commenting on this opinion of Euler's, remarks that "most reasoners seem now to consider comets' tails as consisting of electric matter;" adding that

"this would account for the undulations and other appearances which have been noticed, as, for instance, that extraordinary one seen by M. Chladni in the comet of 1811, when certain undulatory ebullitions rushed from the nucleus to the end of the tail, a distance of more than ten millions of miles, in two or three seconds of time." To this we may add the somewhat bizarre theory suggested by Sir John Herschel, that the matter forming the zodiacal light is "loaded, perhaps, with the actual materials of the tails of millions of comets, which have been stripped of these appendages in the course of successive passages round the immediate neighborhood of the sun."

Now, hitherto no comet with a sufficiently brilliant tail for spectroscopic analysis has appeared since Kirchhoff's invention of that mode of research. Already our physicists had been looking forward anxiously for the appearance of such a comet as Donati's or Halley's. But Angström's recent discovery, and the evidence which seems to associate the tails of comets with the auroral and zodiacal lights, render our spectroscopists doubly anxious to submit a comet's tail to spectroscopic analysis. It is far from being unlikely that three long-vexed questions — the nature of the aurora, that of the zodiacal light, and that of comets' tails — will receive their solution simultaneously.

I had scarcely completed the above pages when news was brought from America that the spectrum of the sun's corona, as seen during the recent total solar eclipse, exhibited the same bright lines as the aurora. The fact that auroral *lines* are mentioned will at once be noticed; but it is to be remarked that the two faint lines which have been lately seen in the auroral spectrum correspond to but a very small portion of the light we receive from the northern streamers. In the spectrum of the corona the same three lines appear, but their relative brightness is different. The brightest line of the auroral spectrum is faint in the spectrum of the co-

rona, while the latter exhibits a bright line where the former has a faint one.

News has also been received that a comparison of the photographs of the eclipse proves the corona, or at any rate its brightest part, to belong to the sun.

Lastly, it has been found that the peculiar phosphorescent light, sometimes visible all over the sky at night, gives the same spectrum (very faint, of course) as the aurora and the zodiacal light.

It is impossible not to recognize the fact that these discoveries point to relations of the utmost importance. The teachings of the spectroscope are too certain to be mistaken. When it shows us such and such lines bright or dark, we may conclude, without fear of being misled, that such and such substances are emitting or absorbing light. What we learn certainly, therefore, from the facts above stated, is this, that substances of the same sort emit the light of the aurora, of the zodiacal gleam, of the sun's corona, and of the phosphorescence which illuminates at times the nocturnal skies. We may conclude, but not so certainly, that the manner in which the light is emitted is also the same in each case. We know certainly that the auroral light is excited by the solar action. We know certainly that it is associated with the earth's magnetism. The opinion, then, which we should form of the source to which the other lights are due is tolerably obvious. So long as electricity was merely used as a convenient way of accounting for any perplexing phenomenon, it was impossible to accept explanations of cosmical peculiarities as due to electrical action. But when once we have reason — as in the case of the aurora we undoubtedly have — to associate electricity with any particular form of luminosity, we seem clearly justified in extending the explanation to the same form of luminosity wherever it may appear.

I believe that the key to the whole series of phenomena, dealt with above, lies in the existence of myriads of meteoric

bodies travelling separately or in systems around the sun. They are consumed in thousands daily by our own atmosphere; they probably pour in countless millions upon the solar atmosphere; and from what we know of their numbers in our own neighborhood, and of the probability of their being infinitely more numerous in the neighborhood of the sun, we have excellent reasons for believing that to them principally is due the appearance of the zodiacal light and the solar corona.

From "*Light Science for Leisure Hours.*"

2. Recent Solar Researches.

SINCE the great eclipse of August, 1868, our knowledge respecting the constitution of the sun has been steadily progressing. One discovery after another has been made, and there really seems to be no reason for believing that we have as yet nearly reached the limits of the knowledge which spectroscopic analysis is capable of supplying. Indeed, the invention of a new form of spectroscope — the ingenious automatic spectroscope of Mr. Browning — promises soon to be rewarded by a series of discoveries as important as any which have hitherto been made. We propose briefly to indicate the present position of our knowledge respecting the great central luminary of our system.

The spectroscopic observation of the eclipse of August, 1868, had shown that the strange prominences seen during total eclipses of the sun are vast masses of luminous vapor, — hydrogen flames, we may call them, considering how largely hydrogen enters into their constitution. Only we must remember that it is hydrogen glowing from intensity of heat simply, and not burning hydrogen, that constitutes

these prominences. Now it had long been recognized that the colored prominences spring from an envelope of a similar nature surrounding the whole surface of the sun. Father Secchi, of the Collegio Romano, in a lecture given to the pupils of the Ecole Ste. Geneviève, had thus, in 1867, described this envelope (whose existence he was the first to recognize): "The observation of eclipses furnishes indisputable evidence that the sun is really surrounded by a layer of red matter, of which we commonly see no more than the most elevated points." One of the first and most interesting results of the eclipse observations was Mr. Lockyer's confirmation of the justice of this opinion. He and Jannsen had independently shown that the existence of prominences can be recognized when the sun is not eclipsed; and the same method supplied clear evidence of the existence of this red envelope, to which Mr. Lockyer gave the name of the *Chromosphere*. Remembering who first indicated its existence as "indisputable," we may conveniently call it Secchi's Chromosphere. (See *note* at the end of this paper.)

Both the chromosphere and the prominences consist of glowing vapor. But there is a difference in their constitution. In the prominences there are usually but very few constituent vapors. Hydrogen is there, and another vapor, whose nature is as yet undetermined, while occasionally there are the vapors of other elements. But in the chromosphere there are commonly several elements, and sometimes there are many.

Here, then, we have above the photosphere of the sun a vaporous envelope, obviously of a complicated structure, and perhaps far more complicated than it has yet been proved to be. For it must be remembered that the lowest layers of this envelope might be composed of the vapors of numerous elements, and yet no record of their existence be recognized. A depth of ten miles would correspond to so small a proportion of the sun's diameter (about the 85,000th part) as to be wholly unrecognizable by any telescopic

power men can hope to obtain. If any of our readers are telescopists, they will know what force lies in the remark that such a distance would subtend about the 44th part of a second of arc, so that no less than twenty-six such distances could be placed between the components of that well-known test-object, the double companion of the star Gamma Andromedæ.*

Next below this colored envelope there is the mottled photosphere, either a white-hot surface with relatively dark pores all over it, or, according to other and better authorities, a surface of white-hot spots spread over a relatively dark background. Here we are describing merely its appearance; what the constitution of this surface may in reality be remains yet to be determined.

Beneath the photosphere there are vast depths of vapor, for when the photosphere is broken through where spots are formed, the spectroscope tells us that the relatively dark regions thus disclosed are filled with the vapors of various elements. We know that the dark lines which cross the rainbow-tinted solar spectrum are caused by the light-absorbing action of the vapors which surround the sun, and these lines are seen more distinctly in the spectrum of a sun-spot than in that of the photosphere.

Now it is worthy of notice that all that has thus far been discovered tends to confirm the theory put forward nearly a century ago by Sir William Herschel. That thoughtful observer recognized in the solar photosphere a widely-extended layer of luminous clouds, while he regarded the light of the penumbræ of sun-spots as coming from a lower cloud-layer. He conceived that up-rushes of vapor, thrusting aside both layers, caused the appearance of a solar spot. We have heard a great deal lately of the English and Conti-

* The view here presented was completely confirmed during the eclipse of last December. Professor Young and Mr. Pye independently recognized a layer whose spectrum showed all the Fraunhofer lines reversed. By observing at the place where the moon had just concealed the last fine sickle of the solar disk, they obviated the effects of diffraction, which render the observation wholly impossible in the case of the uneclipsed sun.

nental theories of the solar constitution; but the evidence we have recently obtained goes far to show that, after all, Sir William Herschel, without the aid of spectroscope or polariscope, formed a juster view of the solar constitution than any which has been recently propounded. He was doubtless mistaken in the view (which he put forward as a mere hypothesis) that the real surface of the sun may be not very intensely heated. We have every reason to believe that the whole mass of the sun is raised to an inconceivable degree of heat. But for the rest, there seems far more reason to believe in Sir William Herschel's cloud-layer theory than in any other which has been put forward in recent times.

Let us consider some of the consequences of such a constitution. Imagine the ascent of vapors of many elements from the fluid surface of the solar oceans. This mixed atmosphere is in reality aglow with the intensest heat and light, so that if we could examine its spectrum separately, we should see the bright lines of the various vaporous elements which constitute it. But intensely hot as it is, it must yet be less hot than the surface from which it has arisen, because the formation of vapor is a process in which heat is used up. And therefore, by a well-known law, the spectrum of the light from the white-hot surface shining through the atmosphere will be a rainbow-tinted streak, crossed by the dark lines corresponding to the various elements composing that atmosphere. But as the lighter vapors in this mixed atmosphere ascend, they reach a region of less pressure, and a region where they can part more freely with their heat. Thus, precisely as the cumulus clouds form in our own atmosphere, so would a layer of clouds be formed somewhat low down in the solar atmosphere. But from the upper surface of this layer the vapors of the elements composing the clouds would rise, again to condense at a higher level, much as the light cirrus clouds in our own atmosphere form at a great height above the layer of cumulus clouds.

The great difference between this process and what takes place in our own atmosphere would consist in the fact that whereas the only kind of cloud which can form in our air is a water-cloud, there can be formed in the solar atmosphere clouds of iron, copper, zinc, and other such elements, each element having its own distinct range, so to speak, within the limits of the solar atmosphere.

Now with such processes as these going on, we can conceive how rushes of heated gas might from time to time thrust aside the cloud-layers; and how where this happened we should occasionally recognize the bright lines corresponding to the more intensely heated gas, as well as the dark lines corresponding to the deep vapor-masses laid bare by the removal of the photosphere. And precisely in this way do the observations recently made by Mr. Lockyer seem alone to be explicable. He sees the glowing vapors above the photosphere stirred from time to time as by fierce tempests—nay, he is enabled to measure (very roughly, of course) the velocity with which these solar winds urge their way through the chromosphere itself, in the neighborhood of the spots. The progress of these hurricanes is often indicated by the appearance of bright lines in those parts of the spectrum where usually dark lines are seen.

Truly Kirchhoff's discovery of the significance of the spectral lines is bearing wonderful fruit! Who would have thought that researches carried on with a few triangular prisms of glass on the light from such a substance as sodium, the basis of our commonplace soda, would lead to the result that solar tornadoes could be watched as readily with the spectroscope as in Galileo's time the sun-spots themselves could be traced across the sun's disk with the telescope? *

From the "*Spectator*" for July 2, 1872.

* I give this paper as it appeared in the Spectator. But there are some points requiring correction. In the first place, the objectionable word *chromosphere* (for *chromatosphere*) should be replaced by *sierra*. Secondly, there is an error as to the absolute priority of Secchi in recognizing the sierra. He went considerably beyond all others in the

Measuring the Brightness of the Sun.

PHILOSOPHERS have examined the chemical brightness of the Sun by comparing it with a terrestrial source of light. For this purpose the intensely bright light produced by a wire of magnesium burning in the air was employed. Experiments showed that the chemical intensity of the sun-light, undiminished by atmospheric extinction, is 128 times greater than that from a surface of incandescent magnesium of like apparent magnitude; or that burning magnesium effects the same chemical illumination as the Sun, when 90° 53′ above the horizon, supposing, of course, that both luminous sources present to the illuminated surface the same apparent magnitude. A totally different relation was found to exist between the visible illuminating power; *i. e.*, the effect produced on the eye, of the two sources in question. Thus, when the Sun's zenith distance was 67° 22′, the chemical brightness of that source was 36.6 times, but the visible brightness 525 times as large as that of the terrestrial source of light.

It may assist the mind in conceiving a sensuous image of

matter, having not only reasoned upon, but seen and photographed the sierra, and having furthermore found evidence as to its nature when studying sun-spots. But Professors Grant and Swan, as well as Von Littrow, the Imperial Astronomer of Austria, had recognised the existence of the sierra before Secchi, and Leverrier had also independently arrived at the same conclusion as Secchi, and at about the same time. I had not known of some of these claims and had forgotten others when I wrote the above paper. This will scarcely seem surprising when it is remembered that the views of Grant, Swan, Von Littrow, and Leverrier had not been made widely public—as Secchi's had—by being published in popular treatises and in lectures. It was with some surprise, therefore, that I found myself charged, not only with ignorance, but, incongruously enough, with injustice also, by a fellow-worker in astronomy, who addressed a letter to the editor of the Spectator, advocating in needlessly warm terms the prior claims of Grant and Swan. It is perhaps unnecessary for me to say that the charge of injustice was wholly undeserved; and I think the writer of the letter would have inferred this had he considered a parallel instance which had recently occurred. For a well-known worker had claimed the same discovery only a few months before as *his own;* and although the subject was specially his, he had not known even of Secchi's numerous public statements respecting the sierra, yet no one thought of charging him with injustice. The writer of the letter could scarcely have forgotten the circumstance, since that worker was no other than himself.

the magnitude of the Sun, if we remember that if the solar sphere were entirely hollowed out, and the earth placed in its centre, there would still be room enough for the moon to describe its orbit, even if the radius of the latter were increased 160,000 geographical miles. A railway-engine, moving at the rate of thirty miles an hour, would require 360 years to travel from the earth to the sun. The diameter of the Sun is rather more than 111 times the diameter of the earth. Therefore the volume or bulk of the Sun must be nearly *one million four hundred thousand* times that of the earth. Lastly, if all the bodies composing the solar system were formed into one globe, it would only be about the five hundredth part of the size of the Sun.

Dr. Vaughan, of Cincinnati, has stated to the British Association, "From a comparison of the relative intensity of solar, lunar, and artificial light, as determined by Euler and Wollaston, it appears that the rays of the Sun have an illuminating power equal to that of 14,000 candles at a distance of one foot, or of 3500,000000,000000,000000,000000 candles at a distance of 95,000,000 miles. It follows that the amount of light which flows from the solar orb could be scarcely produced by the daily combustion of 200 globes of tallow, each equal to the earth in magnitude. A sphere of combustible matter much larger than the Sun itself should be consumed every ten years in maintaining its wonderful brilliancy; and its atmosphere, if pure oxygen, would be expended before a few days in supporting so great a conflagration. An illumination on so vast a scale could be kept up only by the inexhaustible magazine of ether disseminated through space, and ever ready to manifest its luciferous properties on large spheres, whose attraction renders it sufficiently dense for the play of chemical affinity."

3. The Cranial Affinities of Man and the Ape.

THE question touching the descent of man from the ape, takes now such a prominent place in the thoughts of so large a number of living persons, that in a manner it has come to be regarded as a necessity for us to make ourselves more intimately acquainted with the reasons inducing so many to follow up the inquiry. In endeavoring to do this, it is naturally impossible to overlook either the striking resemblance of the ape to the human being, or the fact that it has not been reserved for us to furnish the first anatomical demonstrations of the existence of that likeness. In the second century after the birth of Christ, Galen, the most celebrated medical writer of antiquity, earnestly recommended all such as were desirous of preparing themselves for acquiring the knowledge of man and his diseases, to apply themselves to the study of the anatomy of some apes that "are nearest man;" * and this counsel was so conscientiously adhered to, till near to the close of the Middle Ages, that it may be said almost all the anatomical knowledge of the physicians of those times rested on the study of the structure of the ape. It therefore excited no astonishment whatever, when, in the seventeenth century, the first ape possessing a human resemblance in the stricter sense, was brought to Europe,† to hear that it was called by the natives of Borneo, Orang-Outang, that is "man of the woods." Nor were any objections raised a century later, when the celebrated naturalist Linnæus, in his zoölogical system, which struck out an

* Claudius Galenus, De Anatomicis Administrationibus. Lib. I. c. 2, simiæ hominis figuræ quam proximæ, simiæ vel maxime homini similes. In the sixth chapter he draws up a list of the animals which in their nature do not differ essentially from man (quæ non multum ab hominum natura recedunt) — apes and their different species, bears, mice, ruminating animals, solipeds.

† Nic. Tulpius Amstelodamensis, Observationes medicæ. Amstel. 1652, p. 283. Table XIII. gives a description of them and Illustrations.

entirely new path, ranged man under the scientific name of *homo sapiens*, with the monkeys and some other mammals, in one great division known as the Primates (Quadrumana).

Since that time, the distinctions between the ape and the human being have formed the subject of diligent research; for the system demands a correct exposition of all the differing, but for that reason, characteristic signs, of each class and species. To this end, the separate bones and the whole skeletons of apes, their muscles, their brain, &c., were subjected to an increasingly careful examination. These investigations, however, although at first apparently very productive of results, in process of time lost much of their significance. It came to be seen that the different classes of apes differed in many respects more from each other than they did from man. This fact became more evident as the apes bearing a close resemblance to man, increased in number, bringing an influx of specimens to Europe; and especially since the year 1847, when the first certain intelligence reached us of the most remarkable of all, the gorilla.

This ever nearer approach to a human resemblance excited considerable uneasiness. That class of persons whose wisdom never fails them, and who seem to have a prescience of all things under the heavens, have taken refuge in simply turning their back on the anatomical sequence of the whole question. They appealed to the subjoined adjective sapiens (wise), adducing it as a proof that Linnæus had acknowledged it was the mind that distinguished man from all other animals. To what end, they asked, all those tedious researches, when to man has been given such a decisive physiological badge as reason; nay, when every individual might himself be acutely sensible of the difference in his own inner consciousness. Carl Vogt * has made use of this style of demonstration, but reversing it, and he has thereby, probably done away with it once and forever. He collected the

* Carl Vogt, Ueber die Mikrocephalen oder Affenmenschen. —Archiv für Anthropologie, 1867. Bd. II. pp. 267, 278.

reports and notices of a large number of human beings, whose minds, notwithstanding they were well advanced in years, had never attained to any real development of the reason; whose intellectual culture did not in all cases come up even to that of the man-resembling apes. In this manner he contrasted (if I may be permitted the mode of expression), manlike (anthropoid) apes with ape-like men; and while at the same time showing that the organization of these ape-like men not unfrequently partook of the monkey type, he arrived at the conclusion that by pursuing the path struck out by him, it would be found "to mount higher and higher up to the common origin of that primary class, from which we, as well as monkeys, are derived."

It would in fact be much easier to pick out certain of the lower animals which are distinguished from their neighbors by the astounding keenness of their instinct, than to remove man from the group of vertebrates. How high a place, for instance, do not ants take over the majority of all the other insects, by reason of their physiological qualities! But would this be any reason for setting them in a class apart? Man then, according to his whole organization and development, must be classed with the vertebrates, not only, however, for reasons drawn from the structure of his skeleton or only of his vertebral column, as the term might lead us to suppose, but for reasons founded on his nervous system, especially on his brain; for this at least every one must admit, that without a brain, nay more, without a good and perfectly developed brain, the human mind has no existence. *Man has a mind and a reasonable will only in as much, and in so far as he possesses a brain, and the latter, again, only in so far as he is a vertebrate animal.*

From what has been said, then, it is not hard to understand that the special research into the resemblance between man and the ape, has also been chiefly confined to the systems of bones and nerves; or to speak more clearly, to the skull and brain. They belong necessarily to each other; and

the presence and development of the one, is a necessary condition for the presence and development of the other. It is therefore to a certain extent allowable, from the bones, to deduce consequences touching the nervous system, and especially from the skull, back again to the brain; a method of reasoning which preponderates, as for instance, in paleontology, the science of the fossil remains of plants and animals now extinct. Let us now pass on first to the important doctrine of the spine or vertebral column.

In all vertebrate animals, it is the *spine* that forms what I might call the base, the firm framework of the trunk. In its early stages the spine is cartilaginous, but soon ossifies in the majority of all classes of vertebrates. It is only in the lower classes of fishes (cartilage fishes), that this cartilaginous stage continues throughout the whole term of existence. All the other fishes, the amphibia, birds, reptiles, mammals, and man, get an osseous vertebral column or spine, which is composed of a variously large, but in the individual classes and species, usually fixed number of separate *vertebræ*. These are strung in a row, either one over the other, or behind each other, and are held together by intervertebral cartilages.

The separate vertebræ, according to their position in the column, are generally found to differ somewhat in their construction; their height, breadth, circumference, and special arrangements varying according to the uses and appliances of that certain region of the body. Although this seems to suggest a great variety in the appearance and forms of the vertebræ, still their fundamental outline remains the same throughout, making it a matter of no difficulty to lay down an ideal plan or model of the type of a vertebra. Every single vertebra (Fig. I.) forms a ring or annulus, moderately curved inwards, to the front of it a thicker and more elevated part may be distinguished, to which is given the name of *vertebral body* (*k*), at each side a lower protuberance,—the *arches* (*b*), and to the back, a part rather more raised

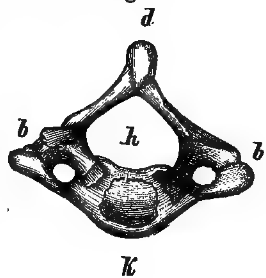
and jutting more outwards, known as the *spinous process* (*d*). Those four parts are found repeated in every vertebra.

For our better understanding, it must further be kept in mind that, what in the human being is called the anterior or front, is in the most vertebrate animals the under, or simply the abdominal side. What in the vertebrate animals is the upper side, comes the back or posterior side in man. But as the human structure will be the most usual subject of our consideration, we shall, with a view to the human posture, as a rule make use of the terms anterior and posterior, before and behind.

In this upright posture, by passing your hand down the middle of the back, you can feel the protuberances of the spinous processes as they lap over each other. These lie so near the surface, that with every motion of the body they are distinctly visible under their elastic covering. The whole row is termed the vertebral column, or *backbone*. The other parts of the vertebræ lie so deep, and partly embedded in flesh (muscle), that it is very difficult to get at them in the living body. Our daily meal, however, presents a regular opportunity for examining the arches and the bodies in our roasted or boiled dishes of mammals, birds, fish, &c. The thicker and more protuberant vertebral bodies may be detected without any difficulty whatever. In younger animals, as for example in calves, still more remains of the original cartilage are to be found.

Let us choose for our demonstrations the vertebra of the neck of a young human being (see Fig. I.). Here we can discover in the cartilaginous base for each of the above named parts of a vertebra, peculiar osseous centres or germs, which may again be composed of several parts, the centre of ossification for the spinous process, for instance, consisting of two

Fig. I.



lateral halves. The older the animal, or the human being grows, those centres too, increase in size, the cartilaginous parts ossifying, and becoming part of the already existing osseous beginnings or centres. In adults, approaching and at length blending with one another, each vertebra comes to present a whole continuous osseous formation. However, the knowledge of the originally separate parts is of the utmost consequence for the understanding of the structure of the skull, as we shall see presently.

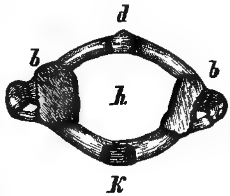
The space enclosed by the osseous ring, the *great vertebral cavity* (*h*), contains the *spinal cord;* and as every contiguous vertebra is furnished with a similar cavity, a continuous canal is formed by the lapping over of the vertebræ, called the *vertebral canal*, and which is carried on to the head. It is firmly closed to the front by the vertebral body and the intervertebral cartilage; to the side and the back, the interspaces between the arches and the spinous processes, by a ligamentous mass. In this manner an effective protection is afforded the all-important spinal cord on the one hand, and on the other, the requisite flexibility is secured for the vertebral column.

At the point where the vertebral body and arch join, we observe on either side a more complicated arrangement. The arch here throws out two small processes, one to the interior, the other to the exterior, by which such a junction with the body is effected, as to leave a small space between, called the *foramen*, which is designed to admit the passage of a blood-vessel, viz., the vertebral artery. The interior process has a slight groove on its upper and under surface. The vertebral arches approximating by twos, the corresponding grooves meet and form the *intervertebral opening*, through which the nerves of the spinal cord pass in and out. Lastly, the exterior processes of the arches throw out all sorts of processes and protuberances to the exterior, as well as to the upper and under sides, and acquire an ever-increasing complexity of form, especially in the pecto-

ral and femoral vertebræ. Some of these processes, as the *articular*, serve to effect the flexible connection of the vertebræ with each other. Others again are designed to be the processes for the insertion of muscles; finally, others establish the connection with adjoining bones, particularly with the *ribs*.

It is unimportant for our purpose to trace the numerous transition forms, now smaller, now larger, which the vertebræ of the different divisions of the spine present. One only is of peculiar importance for our present examination, for which reason we shall bestow on it a special attention. It is situated on the topmost cervical vertebra, and is the bearer of the "globe of the skull," wherefore, even in the days of antiquity, it received the poetic appellation of the *atlas*. This vertebra is distinguished from all the others by the absence of the spinous process, and the body, even in its full-grown stage; and by the greater part of the osseous substance being pressed together into two lateral heaps, the so called lateral masses. For which reason it is usually described as an annulus composed of an exterior and interior curvature, and the two lateral protuberances. But the examination of an immature atlas shows, that all the essential parts of a vertebra are present even then. In the anterior half of the annulus is to be seen, as we already know, the osseous centres (Fig. II., *k*) for the vertebral body; but be it remembered, it is diminutive from the beginning, and its growth soon ceases, leaving it only a gentle swelling prominence or knob. Originally separated by a long cartilaginous portion, the arches (*bb*) join it, each having its separate independent osseous centre distinguishable as the transverse process, articular process, and foramen for the vertebral artery; they turn into the comparatively strong lateral protuberances, whose grooved articular surfaces secure a flexible junction

Fig. II.



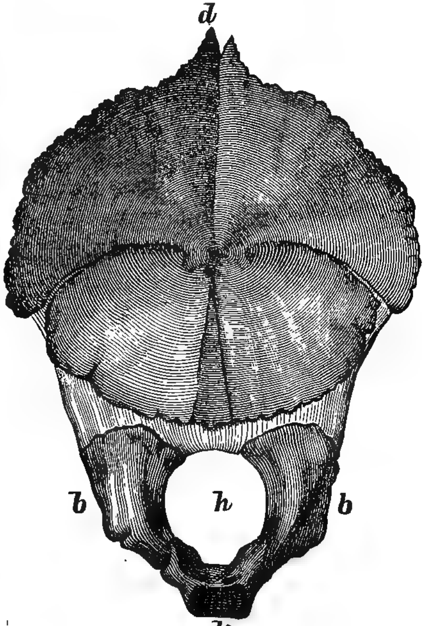
with the head; for in order to effect the lateral motions of the head, the atlas is not, like all the other vertebræ, furnished either above, or below with that intervertebral cartilage. Lastly, on the posterior division of the ring or annulus, we may observe a gentle rising, a suggestion of the spinous process (*d*), which springs from two parted osseous centres.

Thus, by this wonderful and efficient arrangement, the atlas forms the most suitable transition to the *cranial vertebræ*, the vertebral nature of which, being so very much harder to detect, has for this reason been discovered only a comparatively short time ago. The human skull, like that of the higher vertebrate animals, is, as far as the main thing is concerned, composed of three consecutive vertebræ, which go by the names of the *frontal vertebra*, the *middle* or *parietal vertebra*, and the *occipital* or *posterior vertebra*. Each of them is composed of one body, two arches, and a spinous process made up of two lateral halves. But all these parts exist under such peculiar transformations, that long preparatory studies were necessary before ascertaining their signification. One noteworthy circumstance alone throws immense difficulties in the way of comparison with the spinal vertebræ, and that is, *the comparatively compact, nay almost immovable connection, not only of the vertebral bodies with each other, but likewise of all the other vertebral parts of the cranium*, — a compactness perfectly adapted to protect that most important organ of our body, the brain, which is enclosed in this structure, against external influences and injuries. The occipital vertebra alone possesses an articular union with the atlas; towards the anterior it is firmly attached to the parietal vertebra, which, in its turn, adheres as firmly, or even more so, to the frontal vertebra.

As the atlas forms the bridge from the cervical vertebræ to those of the cranium, so the occipital vertebra, by reason of its shape, is the cranial vertebra, that is easiest to explain. We must, however, again base our examination of it on the undeveloped, immature state, in which (see Fig. III.) all the

parts essential to a vertebra, are most clearly discoverable. To the front, as you are aware, lies that peculiar bit of bone called the vertebral body (*k*), differing from the bodies of other vertebræ only in having a more flattened form. Connected laterally with this on either side by cartilage, is the arch (*b*), which by means of its marked condyloid processes, approaches the lateral protuberances of the atlas, on which its articular centres rest. Towards the back, again parted by a cartilaginous suture, rather broader than the last, we come to the spinous process (*d*), such an enormous piece of bone, that it far exceeds all the other parts of the vertebra in size, and for this very reason has been so difficult to explain. Look at this spinous process; it forms a broad, flat, concave lamina, rather thin for its size, which circumstance very soon procured for it the name of the *squama occipitalis*.

Fig. III.



It is that part which forms the back of the head, easy to be felt from its bulging outwards; and it is at the same time the only spinous process of the cranium, on which can be still quite distinctly felt a real osseous protuberance externally, a continuation as it were of the backbone. These different parts of the back of the cranial vertebra surround, —

and always in the form of a circle,—the *great occipital foramen* (*h*), being the continuation of the vertebral canal, and indeed through which the spinal cord passes without interruption up to the brain.

Obviously enough, then, the change in the structure of this cranial vertebra, as contrasted with the spinal vertebræ, is chiefly denoted by the broad and flat expansion of the spinous process. The peculiarities of the other two cranial vertebræ partake of this same character. By a still further enlargement of the spinous processes to *spinal laminæ*, and at the same time as already mentioned, a disappearance of every external protuberance, of every node, every apophysis, the upper part of the cranium, the so called Calvaria or *brain-pan*, acquires that smooth, rounded appearance, which is the peculiar adornment of the human skull. Corresponding in like manner to the spinous process, is the *frontal bone* of the anterior vertebra, that large osseous lamina reaching down to the sockets of the eyes, and which forms the support both for the bare part of the forehead, and for the front portion of it which is covered with hair. Although this likewise originally consisted of two lateral halves, yet in most human beings it grows together at an early stage, to one uniform piece of bone like the squama occipitalis. It is only amongst the few it remains open through life, the above being the rule with the spinal laminæ of the centre vertebra which occupies the region of the crown of the head and the sides, and therefore bears the name of *parietal* or *vertical bone.*

Hence, as a rule, the calvaria of the adult (and the higher vertebrate animals), consist of four spinal laminæ, of which two belong respectively to the anterior and posterior vertebræ, and two to the centre vertebra. The whole meet closely, and are further held together by *sutures*, that is, firm fibrous matter. Amongst themselves, however, we discover in many respects a confusing variety. While, for instance, the squamous bone of the occiput, at a very early stage, grows together inseparably with the arches of the

occipital vertebra, by the ossification of their cartilaginous union, the frontal and parietal bones usually remain apart from their arches throughout life, disconnecting sutures forming on the contiguous borders. Easy as it therefore is, either from an artificial or accidental separation of the cranial bones, to actually see the connection of the several parts of the occipital vertebra with your own eyes, so in the same degree was it difficult to discover those bones which must be regarded as the arches and bodies of the frontal vertebra.

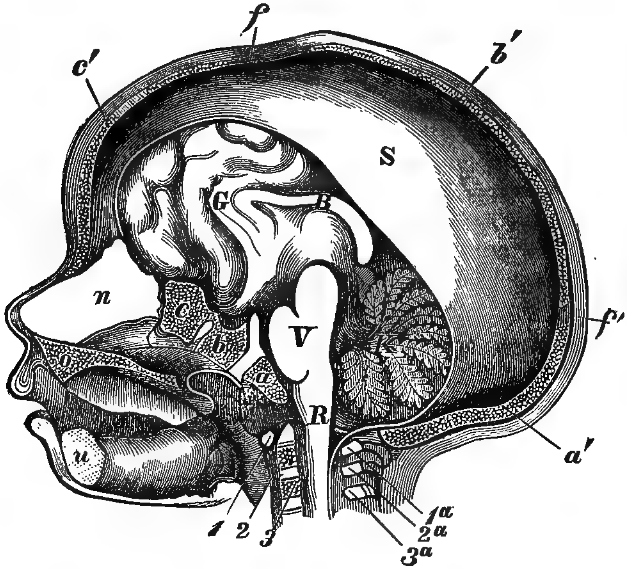
In order to comprehend how this is, we must begin by excluding from our investigation all the *bones of the face*, for these are as little component parts of the cranium, as the ribs and pelvis are of the backbone. The bones of the face, principally those of the upper and lower jaw, are simply attached to the cranial vertebræ, but for the rest in no connection whatever with them. They represent the system apart, of the highest value for the scientific and artistic study of the head.

We must further take into consideration that, what is the fore part in the spine, is the under part in the cranium, and vice versa; what forms the posterior part in the spine, in the skull lies at the top, and partly to the front. The human head, having comparatively the strongest inclination over towards the upright vertebral column, there is hereby formed between the atlas and the body of the occipital vertebra, an angle open to the front, the upper arm of which runs off in the direction of the *base of the skull*, and reaching to the root of the nose. Here, again, the occipital vertebra presents a most characteristic transformation, its body always extending more to the front in comparison to the spinal lamina. On the other hand, in the middle cranial vertebra, which forms the *crown*, properly so called, the body lies downwards; and in the frontal vertebra, which presses quite forward, the body obtains a position removed even still farther to the back.

Those different positions can be best seen by examining

the section of a head (that of a new-born child being preferable), divided from before backwards near the median line, through head and neck. (See Fig. IV.) Looking at it,* you perceive at once the immediate connection of the spinal cord (R) with the pons Varolii (V), and through it, with the cerebrum and the cerebellum (G and K). You

Fig. IV.



may further trace how the brain, in its perfection,† suddenly sends forth such a quantity of compound formations, and in such an abundance and variety, that makes a markedly increased expanse of space necessary. The vertebral canal, therefore, extends away on the upper side of the great occip-

* The Plate is taken from Virchow's "Untersuchungen über die Entwickelung des Schädelgrundes im gesunden und kranken Zustande und über Einfluss derselben auf Schädelform, Gesichtsbildung und Gehirnbau. Berlin, 1857." Plate I., Fig. 1, also to be found in Virchow's pamphlet: Gœthe als Naturforscher, Berlin, 1861. p. 105. The reader's attention is likewise called to Virchow's treatise, "How man grows." Berth. Auerbach's Volkskalender, 1861, p. 95.

† The cerebrum consists, as you are aware, of two lateral halves, called hemispheres.

ital opening, to the roomy *cavity of the skull*, while the arched *calvaria* is attached to the rather narrow and uniform vertebral column.* As has been already explained, the calvaria is divided into skull-cap and skull-base, and the former, as we can perceive, is formed by the occipital squamous bone (*a'*), the parietal bone (*b'*), and the frontal bone (*c'*), connected with each other by sutures (*f* and *f'*).

In order to discover the bodies belonging to the above, we must cast a glance at the base of the skull, and here we behold, under an easily recognizable form, the body of the occipital vertebra (*a*). In the front of it, — in the child separated by a strong synchondrosis (cartilaginous union), — is to be seen the body of the central cranial vertebra (*b*), which even in a new-born infant is but imperfectly separated by an intervertebral cartilage, from the bodies of the frontal vertebra (*c*). In front of this you observe a mass of cartilage (*n*), which reaches on the one side to the base of the skull, forming here the ethmoid bone; on the other it serves as the base for the septum of the nasal cavities. This partition wall reaches to the upper jaw (*o*), which faces the nearly isolated lower jaw bone (*u*), the inferior maxilla.

In this sketch, which has at the same time revealed to us the essential elements of the facial skeleton, it is the position of the bodies of the frontal and parietal vertebræ that interests us. How has it been possible to overlook an apparently so obvious relation for so long? There are two reasons which may be given in explanation. Formerly it was not customary to bisect the skull in the manner here described, and it was consequently necessary, first, not only to break down prejudice, but also to overcome the idea of preserving the connection of the bones. Again, the true relation can be observed only in the skulls of quite young children, a relation

They are united in the middle by the corpus callosum cerebri (B), and parted by the falciform process (S), a fibrous membrane, which presses in between them.

* In Plate IV., the numbers from 1 to 3 indicate the three uppermost cervical vertebræ, those from 1ª to 3ª the spinous processes belonging to them. Between the bodies is to be seen the intervertebral cartilage.

which becomes less and less perceptible with every year, so that in adults it is hardly distinguishable. For in the adult, we no longer see distinct and separate vertebral bodies, but one solid bit of bone, the *os tribasilare*, which is formed by the cohesion of the bodies of all three cranial vertebræ. Till about the twentieth year of age, the body of the occipital vertebra in the posterior portion of the basilar process, remains still separated by cartilage, hence its signification was less mysterious. On the other hand, the consolidation of the anterior vertebral bodies takes place so early, that from olden times they were regarded as a single inseparable piece of bone, and known under the common appellation of *wedge-bone* (sphenoid). Later times have taught us, that the anterior sphenoid (*c*) is the body of the frontal bone (*c'*), and the posterior sphenoid (*b*) the body of the parietal bone (*b'*). The connection between these parts is effected by means of special "wings," which again correspond to the arches of the common vertebra. One can thus imagine the whole of the skull-cap as composed of three annular vertebræ, placed one behind the other, and in the closest connection with one another.

The disclosure of this relation, so simple in itself, and still so mysterious, is altogether based on the increasing insight gained into the "*history of development*." This science is still in its infancy. The method of thought to which it has given birth, even the peculiar direction observation takes in it, and by which it has been created, was hidden from antiquity and the Middle Ages. It is the glory of the Germans to have discovered it; and strange enough we owe it to our great, our immortal poet. Starting from the study of physiognomy, which Lavater had encouraged him to undertake, Gœthe applied himself to anatomy. Ever and again recurring to these studies during a course of years, he acquired great acuteness of insight into the fundamental laws of organic life. As the poet said himself, he endeavored to discover "the idea of the animal," and lo! what had hitherto

been a sealed book to every one, disclosed itself before the prophetic gaze of such an inquirer. A strange incident brought his thoughts hereon to a conclusive result. On his second journey to Italy (1790), while visiting the Jewish burying ground in Lido, his attendant picked up from the shore a fractured ram's head, which, from the state of decomposition in which it was, showed the several parts clearly. "Here," said Gœthe, "I had the whole together in its most general outlines." *

Later, it is true, the priority of the discovery was disputed. Some authors have tried to ascribe the honor of the first conception to the old wizard bishop of Ratisbon, Albert the Great, and to Peter Frank, the celebrated clinical physician. I have already taken occasion to show in some other place that this is not correct. The only man whose claims have any right whatever to consideration is Oken, the celebrated anatomist and zoölogist of Jena, and a younger contemporary of Gœthe's. But he himself has fixed as the date of his discovery, the August of the year 1806, when, while taking his holiday trip to the Hartz Forest, and slipping down the steep side of the Ilsenstein, he suddenly saw at his feet "the most beautifully bleached skull of a hind. To pick it up, to turn it round, to examine it, was the work of a moment. The revelation came upon me like a flash of lightning — it is a vertebral column! And since that time, the cranium has been a vertebral column." Oken indisputably deserves the praise for having first brought the idea within strict scientific bounds, and gaining general recognition for it; but that it was *first* revealed to him, is not the case. It is undoubtedly a strange coincidence that on both occasions an accidental circumstance while travelling should have presented the decisive object to the prepared and practised vision of a thinker and of an investigator; still the honor of having had the vertebral theory discovered through it, must be accorded to the ram's skull.

* Compare pages 61 and 102 in above-mentioned little work, "Gœthe als Naturforscher."

To the further perfection and universal establishment of this theory, another science as new, and likewise born of the German mind, has powerfully contributed; I allude to *comparative anatomy*, discovered by Kielmeyer, a quiet scholar of Tübingen, and the teacher of the renowned French zoölogist, Cuvier.* Based on this groundwork, the relation of man to the higher animals, since that time classed under the term vertebrate animals, has appeared in quite a new light. The conviction has been gained, that a *common idea* must be discovered in the structure, not only of those animals that have come to their full growth and perfection, and which hitherto have formed almost exclusively the subject of the scientific discussions of the systematists, but above all, of those which are in a state of development. From the simplest form of an egg, often microscopic in its dimensions, is built up a typic series of forms developing uninterruptedly the one out of the other, and rising at length to the perfection of organism. The higher the progressive step is, which we have before us in the history of individual organism, and the nearer it is of reaching its highest perfection, the more varied do the different organisms appear. Family is distinguished from family, genus from genus, species from species, individual from individual. Reverse the process, and the farther you trace back the simple organisms to their beginnings, the fewer stages of their development they have to run through, and the greater the resemblance between the individuals, the species, and the genera, nay, even between the grand divisions or families of the class of vertebrate animals. *All development is a process of dissimilarization, and every higher animal organism, in a lower stage of its evolution, resembles an inferior organism.*

This fact was acknowledged in the full weight of its importance, even by Gœthe's nearest contemporaries, and they clothed it in even a stricter formula than we are accustomed

* "Gœthe als Naturforscher," p. 123.

to do. John Frederick Meckel, the acute anatomist of Halle, in the year 1812, wrote as follows: "The same scale of gradation which is presented by the whole animal kingdom, the members of which include the different races and classes, as well as the extremes of the lowest and highest animals, can likewise be followed in the development of every higher animal; for from the moment of its existence, on to the period of its perfection, in respect both of its internal and external organization, it essentially passes through all the forms which constitute the permanent condition of all those animals belonging to an inferior grade. The series of those forms are more numerous according as the animal is larger and more perfect, for they necessarily increase with the number of every inferior class they have left behind." * He however adds, "It is not probable, at least it has not been observed, that a lower animal can overstep its class and assume a higher form." But he has sought in numerous examples to show, that through obstacles in the entire development, or in that of separate organs only, any higher animal may stop at a lower stage, and in consequence grow to resemble the animal corresponding to that stage. It is scarcely requisite for me to add, that in this respect he does not except the human being.

Indeed, there are cases of human beings showing a certain resemblance to animals (theromorphy). The fabulous histories of all peoples is filled with such tales. The story of the beautiful Melusina, and also numerous portions of Egyptian and Grecian mythology may serve as examples. Thus we encounter on the one hand, many human beings bearing a resemblance to animals, and on the other, many animals bearing a resemblance to human beings, the monkey naturally claiming here a prominent place. Now, the above observations having been proved beyond a doubt, what thought seemed more pertinent, than that man was derived

* Joh. Friedr. Meckel, Handbuch der pathologischen Anatomie. Leipzig, 1812. Bd. I, S. 48.

from the monkey! This idea, already long known, though but timidly uttered, and then mostly in relation to the negroes, by the slave-holders in the South States of North America, gradually gathered greater certainty, and growing bolder, counted many adherents in Europe, when through Darwin's celebrated book on the Origin of Species (1859) the notion of a progressive development of organic nature, from the meanest beginnings to the highest forms, has attained a greater and more extended popularity. Darwin has himself not pushed his system so far as to carry back the pedigree of man to the monkey.* But Carl Vogt, Huxley, Hæckel,† and others have done so.

Here, however, I must once for all refute a widespread, but false assertion. No naturalist down to the present time, has even affirmed, that any of the known, and non-existing families of monkeys, is the ancestor of man. In America there are no anthropoid apes, — none in the true sense of the word, — bearing a human resemblance. Such are to be found only in Africa and Asia; the chimpanzee and the gorilla in the regions of the former continent, and the orang-outang and gibbon in those of the latter. Now American writers,‡ even before Darwin, have laid considerable stress on the fact that the home of the anthropoid apes was also that of the lower organized human races, and that both in many respects, as for example in complexion and conformation of the facial lines, offer striking parallels. Herefrom they have deduced a variety of origins for men and apes; and indeed the conclusion which Vogt drew was pretty self-evident, viz., that the negroes have one and the same origin with the apes of Africa, as the negritos of the Sunda Islands

* This was written before Darwin's new book on the descent of man was published.

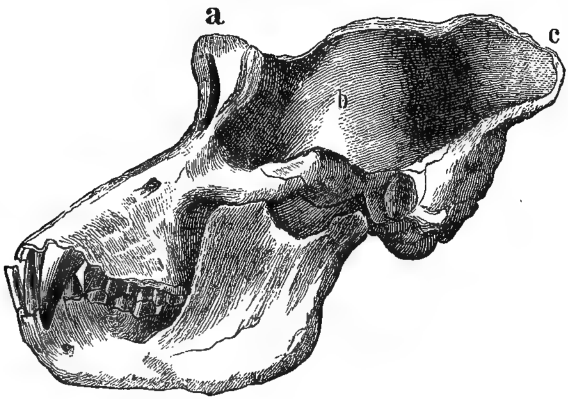
† Carl Vogt, Vorlesungen über den Menschen. Giessen, 1863. Bd. II. S. 260, 276. — Thom. H. Huxley, Zeugnisse für die Stellung des Menschen in der Natur. Aus. dem Engl. von V. Carus. Braunschweig, 1863. S. 120. — E. Hæckel, Ueber die Entstehung und den Stammbaum des Menschengeschlechts. 1868.

‡ J. C. Nott and Geo. R. Gliddon, Indigenous Races of the Earth. Philadelphia, 1857, Pl. XIV. pp. 548, 646, 650.

have with those of Asia. But Vogt has not said either that the gorilla or the chimpanzee is the ancestor of the negro, or that any certain Asiatic ape is the forefather of the negritos and the Malayans.

Indeed, this very remarkable fact has been pointed out in the morphology of the monkey, viz., *that the resemblance of the baby monkey with the human baby, is much greater than that of old monkeys with perfect full-grown men*. And nowhere does the analogy come out more strongly than in the construction of the cranium. The lesser bulk and prominence of the facial bones, the less marked shape of the eye

Fig. V.



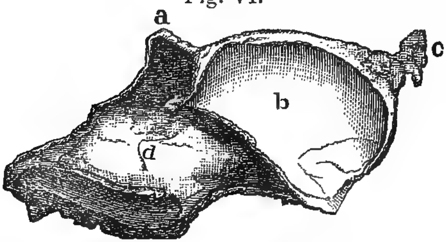
and the parts around it, the smooth arch of the calvaria, the general form of the skull-cap, the relation to one another of the cranial vertebræ, brings the head of the baby ape so near that of the human infant, that the resemblance may indeed be called "terrible." *But with every month and year of life the skull of even the most anthropoidal ape grows more dissimilar to the human cranium.*

Let us look at the head of one of those gorillas so celebrated in recent years, and whose home is in the tropical southwest of Africa. The full grown animal has an enor-

mous head (Figure V.); but that part of it which we find in a state of high development is not the skull-cap proper (*b*), the receptacle of, and at the same time the standard for the bulk of the brain; it is not the cranial vertebræ, but rather the external osseous appendages. The enormous jaw bone protrudes in its repulsive ugliness, with its great fangs superior in bulk to all the rest of the skull. The lower jaw, in its breadth and power, attests to the strength and size of the masticating muscles which are inserted in them. Corresponding to this, is the extent and arch of the cheek bone, under which these muscles must pass to be inserted in the skull. But while in man they only occupy the region of the temples, and the side part of the parietal bone, they here cover the whole surface; and coming from both sides almost reach the median line, along which runs an elevated ridge of bone, in the gorilla terminating behind in a regular bony comb or crest (*c*). This crest is the visible continuation of the backbone, which in the human cranium shows no traces of continuation; it is the repetition externally of the prominent spinous processes of the vertebral column. But, not only in the median line, but also in the direction of the back and side, we find a curved bony ridge marking the point of insertion of the temporal muscles. Added to this comes lastly the great rugged curve of the ridges of the orbit (*a*), completing the impression of savageness and bestiality.

Still more striking is the extraordinary disproportion between the cavity of the skull proper, and the external appendages, which may be seen in a longitudinal section of the skull (Figure VI.). The cavity of the skull proper (*b*) does not exhibit a much greater superficies than the

Fig. VI.



cavity of the nose (*d*). At the crown (*c*), like a serrated promontory, the crest towers over the arch of the calvaria, while to the front the cranial cavity retreats to make way for the great frontal sinus (*a*). Comparatively little space is left for the brain; it is almost only the more animal parts, especially the apparatus for masticating and breathing, that develop. *Of all the parts of an ape's head, it is the brain that grows least.*

If we now take into consideration that the brain of the anthropoid ape contains all the chief parts of the human brain; that the brain of the infant approaches that of the baby ape in comparative size, it is obvious that the ape at some stage of development strikes out a path opposed to that usually selected by the human being; that therefore the ape, its head not excepted, would, through further growth, only become more and more dissimilar to man. Even the largest ape keeps its baby brain, although the jaw may be that of an ox. The natural deduction therefore seems to be, that *by progressive development an ape can never become a man*, nay, rather, that this very development has created the deep gulf between them. In the little Uistiti, for instance, in the east of Brazil, the very lowest in the scale, the bony framework of the head retains a stronger resemblance to man than in the anthropoid species.

If, then, it is the same great law of morphology that determines the structure of the ape, as that of man in its base, still the difference in the character of the two species is displayed in no direction so strikingly as in their corporal development. First, there is the *duration* or term of life, and all connected with it; next the *rapidity* of development in the whole individual, as in the several parts; all which is very different in the ape as compared with the human being. Apes, generally speaking, have a short life and a rapid growth; they are born in a state of bodily and intellectual maturity, which is frequently enough the case among animals, though never among men; they attain their perfec-

tion in a few years; and an early death puts a term to their existence. Although we have no exact data to guide us in fixing the absolute duration of the life of the anthropoid apes, it is still open to doubt if any of them ever attains that age at which the human body arrives at its full growth. This at least is certain, that even the tallest apes are perfectly developed when man is still in his earliest youth; and they are pubescent, when man has scarcely outgrown childhood. Still more characteristic, however, is the *distribution of the period of development to the several parts of the body*. In the ape the brain, as a rule, has reached perfection before the period of its shedding its teeth; while in man it then takes its first real step to perfection. As soon as the milk teeth have been replaced by the second, it is then that that rapid growth of the jaw and facial bones commences, that enormous enlargement of the external parts of the bones of the skull, which are the most decisive marks of its animal character. This difference carries all the more weight with it, seeing the ape casts its teeth at a far earlier period than man. It is not our intention to go over the other parts of the body in like manner; let it suffice for me to state, that the differences are still more marked in other sections of the skeleton. The extension of the posterior section of the vertebral column to a tail, the disproportionate length of the arm, the diverging form of the pelvis, all those peculiarities vary in the different species, but none ever accept the human shape. That is intelligible; for not only the "man of the woods," but more or less all apes, are climbing animals. The tree is their natural home; no species can, in the proper sense of the word, walk.

Hence the hopes of those naturalists who have desired to find in the ape the progenitor of man, are deferred to the future. The circumstance of the gorilla having been comparatively but recently known, reanimated this hope, which has received fresh encouragement; further, from the discovery of some extinct species in the older strata of the earth's

crust, likewise made only some thirty years ago. Not only in the East Indies and the Brazils, but also in Europe, chiefly in England, France, and Greece, fossil remains of monkeys have been dug up, which fit in to the now existing families. None of those classes, however, fill up the gap between man and the ape; and for the present it is out of our power to say whether research may ever succeed in fitting into each other, through actual demonstration, all the intervening links of the species man and the species ape.

As I have already stated, Vogt has struck out another path of investigation, in order to fill up the gaps. Since some time past, cases have come to light where now and again, in otherwise healthy families, members of the same have not progressed to a perfect development of skull and brain. From their, at the same time, having stopped on the lowest grade of intellectual cultivation, it was customary to denominate the condition as that of congenital idiocy; and the objects themselves as *microcephali* (small heads). Undoubtedly their brain as well as their skull presented a very much greater resemblance to the brain and skull of the monkey, than is to be found among perfectly organized men. The comparatively vigorous growth, indeed, of the jaw and facial bones, imparts something in a very high degree monkey-like to the appearance, justifying the employment of the expression "ape-like man."

But no greater value is to be attached to this expression, than to that of anthropomorphous to the highest species of apes. Just as little as these apes are men, notwithstanding their human resemblance, so little are idiots apes, notwithstanding their resemblance to monkeys. They are merely examples of impeded development, in the sense of Meckel, and all the more, as the stoppage in the development by no means changes the whole structure of the body in a like degree, but is essentially confined to the brain and skull. It is then only one region of the body that assumes this resemblance to the brute. All the other parts of the body retain

their human resemblance so entirely, that an examination confined only to that region would justify us in coming to the conclusion conveyed in the term.

The history of human malformations shows us similar *local arrestment*, *along with resemblance to the brute*, under an often still far more surprising form. With reference to this, Meckel * with great justice had already attached some importance to the heart and vascular system. "In fact," says he, "on a closer investigation into most of the abnormal conditions of the form of the heart and the source of the vessels, we meet both the higher and the lower animal forms, and later as well as earlier stages of development." Nay, he adds, and the remark is of peculiar importance, "the stage which constitutes its abnormal formations, is in so far still more interesting than that which represents the embryonic and the animal series, *because from the union of higher and lower shapes arising from one part outgrowing the others*, a variety of forms is produced; a remark which is in so far deserving of attention, as it furnishes the explanation for the not always perfect resemblance between the abnormal shape of the heart, and its embryonic and animal conditions." He then describes human hearts which have the character not merely of those of the mammals, but likewise such as have the character of the higher and lower reptiles, of fishes, and even of insects and crabs.

It may perhaps not be unimportant to place before you, out of the numerous list of human deformities, one of the most striking; and it is that in which the upper and lower members are so stunted as to give such a child the external appearance of a seal. Geoffroy Saint-Hilaire † has applied to this the term Phocomele; and with just as much right we might call such individuals *seal-folk*, as those resembling monkeys ape-folk.

* Meckel a. a. O. S. 412, 419.

† Isid. Geoffroy Saint-Hilaire, Histoire des anomalies de l'organisation chez l'homme et les animaux. Paris, 1836, T. II. p. 208.

Further, there are human monstrosities devoid of both head and heart. Are we to regard them as reminiscences of the lowest order of fishes, the amphioxus, standing at the bottom-most step of the scale of vertebrate animals, also being endowed with neither head nor heart?

We see then, that in this way too much can be proved. The history of deformities might be turned to account to show that every man, in his earlier stages of development, has not only been like all animals, but really corresponds to all species; that in fact, at some time, he really has been, or may become, a fish, a seal, a monkey.

Another result of experience must here be taken into consideration, as follows: The observation has not rarely been made, that in the artificial breeding of domestic animals, certain varieties *revert* again to the original species. Darwin, in his dissertation on the Origin of Species, has traced this reversion, or as it is called, *atavism*, with the greatest assiduity, and therefrom drawn most important deductions, and in many respects incontrovertible. He goes even so far as to assume, that not only does variety revert to species, but likewise that species reverts to species. Vogt has extended this theory to the microcephals, but indeed, in its very widest application, that of the reversion of genus to genus.

If what he states were correct, regarding the correspondence between the skulls of idiots and apes, it would in every case be a highly significant fact. He maintains that * "the skull of an idiot found in a fossil state, and even somewhat injured, the lower jaw and the teeth of the upper one, for instance, being wanting, would unquestionably be taken for the skull of an ape; and that not even the slightest indication would be discoverable in such a skull to justify a contradictory conclusion." I must first remark to this, that Vogt arrived at such conclusions by comparing an idiot's skull with that of a chimpanzee, according to which, if we are to be consistent, we should regard the chimpanzee as our progenitor. This, however, contradicts the fact that

* Carl Vogt, Vorlesungen über den Menschen. Bd. I. S. 252.

the gorilla resembles man in a still more striking degree than does the chimpanzee. The admission that the jaw of the idiot and the ape cannot be confounded, must not be underrated. When we consider that Lartet, from a fossilized fragment of an under jaw, found in an old marl stratum in the south of France, not only proved the existence of an antediluvian monkey, but even demonstrated the fact of a new family resembling man very closely, called the dryopithecus, it seems we ought to be able to judge of the value of the above concession. But with all that, I still doubt Vogt's main assertion. Even a microcephalic skull wanting all the face, excepting the bones of the nose, would suffice at the first glance to show the difference from the skull of a monkey; while a closer comparison would most assuredly furnish proofs of more undeniable distinctions. It suffices to call the position of the great occipital foramen, and the relation of the basilar process, which relation, however, must be shown on young idiots, and monkeys of a higher age, not on full-grown idiots and baby monkeys.*

But my chief ground of objection to Vogt is, that without any ceremony, he classes *diseased* and *monstrous* conditions along with normal and typic conditions. This, even from the point of view of a declared advocate for the theory of descent, cannot be ceded; for the origin of new species and varieties has only then a meaning, when the single individuals of the species or variety are so constructed as to be able to lead an independent existence, or, if necessary, to carry on the struggle for existence. Consequently a species of variety cannot exist if its individual members are so helpless that they are unable to do anything for their own preservation, when they have not even the power to attach themselves as parasites to some higher being. And this is the case with the microcephals. Their idiocy is an obstacle to their undertaking any sort of independent labor which

* C. Aeby, "Die Schädelformen des Menschen und der Affen." Leipzig, 1867. In page 82 a stress has beeen justly laid on the fact, that in all investigation the mistake has been too frequently made of only comparing the baby-ape with the full-grown man,

might promote self-preservation. It falls to the family or to society to maintain them. Quite apart from their incapability of propagating, or, in other words, of actually originating a species or variety, their intellectual condition, i. e., their brain, is so defective, that even did such a species or variety exist, it would at once perish, without any struggle whatever, for existence. Along with this defect of understanding which many a monkey all but possesses, the microcephali are also deficient in instinct, which in the new-born monkey even, seems in an astonishing manner to fit it for performances as wonderful, as they are suitable and to the purpose.* All such power is wanting in the microcephalic idiot; he labors under the misfortune of an imperfect brain; he suffers from a defect without any corresponding compensation. *He is a human being partially changed by disease, but he is not a monkey.*

A partial, merely local change, is certainly one of the most common sights, either in the structure of the variety or the race, for which reason, while on the one hand the natural or physiological changes are extremely apt to be confounded with the diseased or pathological ones, it is on the other, imperatively necessary to consider both in relation to each other. This view especially holds good in an examination into the nature of *inheritance* (here understood in the sense of transmission of hereditary qualities), about which a few remarks of mine to this effect were published some time since,† and when I in particular pointed out that *inheritance* did not always bear reference to the same sum of qualities, or of the signs within the range of the race or the species, but rather that those symbols might be increased or diminished in the separate generations. It is, therefore, possible that a defect in development, caused by disease, may be hereditary, and give rise to a variety or race. Think for a moment of the pug nose, which is not confined to dogs

* Alfred Russell Wallace (The Malayan Archipelago, the Home of the Orang-Outang and the Bird of Paradise). Vol. I. p. 59.

† Virchow, Ueber Erblichkeit. (Deutsche Jahrbücher für Politik und Literatur. Berlin, 1863. Bd. VI., S. 357.)

alone, but is to be found in swine, horses, and so forth. But for the establishment of a variety or race, transmission is imperative, and transmission is not possible without propagation. Where this is not, no species can maintain itself. In the list of human monstrosities, one of the most remarkable is the so-called "*Cherub*," in which both trunk and limbs are wanting, the head being the only part that develops; this produces the total impression of those pictures of heads so often painted by the artists of the Middle Ages, in or on the clouds. Could such a "Cherub" live and propagate, a genus of *the trunkless* (acormi) would arise, representing animals endowed with spirit. Unfortunately, they are of as little use as the microcephals for the theory of atavism, for they always maintain themselves at the expense of a twin-brother; and any hope of their spreading, or their attaining sovereignty in this world, is nugatory. They suffice to illustrate the reverse of the doctrine of reversion.

It may, therefore, be distinctly affirmed, that an actual proof of the derivation of man from the monkey, has hitherto not been produced; and, in my opinion, the evidence required must consist in the being able to point out *a certain species of monkey*. A general likeness to the species, showing us how man resembles one monkey in one thing, and another in another, is not sufficient. But all naturalists agree in saying that none of the known apes is this definite primary species. And therewith is the verdict pronounced, that all investigations down to the present day have not led to evidence, but merely to conjectures.

Is the question therewith decided? For the natural philosopher most assuredly not. Great districts of the earth are still quite unknown as respects their fossil creatures, and amongst those districts are just the homes of the anthropoidal, or man-apes. Tropical Africa, Borneo, and the neighboring islands, are, as regards the above object, still virgin soil. One single fresh discovery can give a new turn to the whole question. The reserve which most naturalists herein impose on themselves, is supported by the small number of

actual proofs for Darwin's theory. Considered logically and speculatively, the so-called theory of descent is excellent. Even before the publication of Darwin's book, I once publicly expressed myself to the following effect: "that it seemed to me like *a necessity of science* to recur to the capability of transition from species to species." * And I added, "There exist at present great gaps in our knowledge. Dare we fill them up with conjectures? Of course, for only by conjecture can the untrodden paths of investigation be opened up." Darwin has done this in the best sense of my words.

In that same aforesaid publication of mine, I continued as follows: "There is, to be sure, another method of filling up the gaps. We may simply accept the religious traditions of the story of the Creation, and thus exclude investigation altogether. But, and I utter it openly, although we do accept the theory of Personal Creation, we have still no right to consider investigation into the mechanical process as inadmissible." Moreover, in all the fables of creation in ancient religions, it is represented as carried out in a more or less mechanical manner. According to the Jewish story of Creation, the first man is formed of the dust of the earth, his mate of one of his ribs; and from this pair are said to have descended all men, therefore all races. Wherefore all men are brethren, the whole genus one species. But is this much-prized unity of the human race indeed so easy to be deduced and understood from the suppositions of the Jewish fable? Has any one already observed the transition of one race into the other? The whole doctrine of the human races rests on our observations of the transmission of corporeal and intellectual qualities. The traditions of the church point to Noah as the progenitor of all races. How are we to imagine Noah to ourselves, and Adam, his progenitor, in a direct line? Prichard, the celebrated English ethnologist, and Bledsoe, the orthodox North American, have not scrupled to set down the first human beings as negroes.† But

* Virchow, Vier Reden über Leben und Kranksein. Berlin, 1862, p. 31. (Held in the German Association of Naturalists and Physicians, Carlsruhe, September 22, 1858.)

† Vide Quotation from Nott and Gliddon, l. c. p. 510.

this does not help us one step farther on than as if they had declared them to be whites; for although it does occur that a negro may be white, and vice versa, still this is only another added to the list of human monstrosities. Notwithstanding his fair skin, a white negro possesses all the other properties of a negro, and no power can make him anything but a white negro. To truly become a white man, all the other parts of his body must likewise be changed; such a change is beyond the limits of any experience hitherto made. Nor has it ever been observed that a negro race has ever really passed into a white one.

On the contrary, the most ancient monuments of art, especially those of Assyria and Egypt, exhibit even at that early period the typic representations of the single races, human as well as those of other animals, as they then existed. Here we are left entirely in the dark as far as experience goes, and it is certainly very characteristic that the advocates for the orthodox view, who take up arms with such warmth against Darwinism, should, with naïve unconsciousness, act in regard to the human races on the very same principle as he lays down for the animal species, without their either being at all able to produce demonstrable proofs. *While facts seem to teach the invariability of the human races and the animal species, both pious tradition and speculative natural philosophy require their variability.*

Hence one should suppose that theology and the natural sciences ought in justice to be meted at least with the same measure. But our feeling rebels against this. It seems unæsthetic to grant the variability of the animal species along with that of the human races, because it inevitably brings us to the question of the derivation of man from the ape. Human pride cannot accord such an approach. Man calls for an insurmountable barrier between himself and the brute; the lord of the creation must construct a peculiar realm for himself within the bounds of created things.

In former times this same sentiment led to similar parti-

tions and divisions within the limits of mankind themselves. Heroes, it was said, were descended from the gods, in order not to mix them up with the common herd. Till far into the Middle Ages, many of the noble European families, in spite of Jewish and Christian biblical belief, carried their genealogical tree up to the Grecian gods; as, for instance, it was customary among generations of rulers to give out they were derived from Æneas, and through him from the goddess of Beauty herself, even from Aphrodite. As late as the year 1466, Albert Achilles proclaimed by pen his convictions regarding the descent of his house, viz., that his forefathers had gone from Troy to Rome, and from thence to Swabia to the ancestral castle of the Hohenzollers.*

Such feelings, however, are not decisive; they have no universal validity. Other countries produce other manners, other views, and other feelings. Among the Indian anthropoids there is one species, the Hulman, which not only enjoys divine adoration, but is likewise thought worthy of the honor of being regarded as the true progenitor of man. A reigning family, whose members bear the traditional name of "Rana of the Tail," maintain their having been derived from the sacred ape.† The Canadian Indians go still farther. They regard the whole living creation as one great society, within the bounds of which man moves the first among his like; between him and the brutes, they say, down even to the toad, exist the closest bonds of kinship. Just as he looks on the wolf as his progenitor, so does he call the bear his brother, the fox his cousin.‡

When we cease to be able to push fact any farther, there still remains scope for sentimental science. From the moral point of view, however, we have no right to overturn the theory of descent, nor is there any reason for our doing so. If man is the last of those transformations, through which the individual member of the animal kingdom has passed,

* A. F. Riedel, Geschichte des Preussischen Königshauses. Berlin, 1861. Bd. I. S. 14.

† A. E. Brehm, Illustrirtes Thierleben. Hildburghausen, 1863. S. 42.

‡ Kohl, Ueber die kanadischen Indianer. (Ausland, 1859, Nr. 3, S. 54.)

he is likewise the highest and the noblest. In every case, it was an immeasurable progress which living nature had made, when the first man was developed out of a lower animal, whether an ape or any other animal, which was at the same time the progenitor of the ape. Nor was the progress less great that man himself made, when in the course of thousands of years he raised himself from the condition of a rude ape-like savage, to that of a citizen in a highly civilized state. If this last idea is admissible, if it does not contradict feeling; if it is, indeed, the foundation of almost all the reflections on culture and civilization, of the spiritualistic writers, then we must suppose that the idea which teaches us to go back to look for our rude and savage progenitors among those cannibals of before and after the deluge, should cause us no emotion, even if they were derived from the brutes. For morally speaking, it assuredly affords a higher satisfaction to think that man has raised himself by his own labor, out of that state of rudeness, ignorance, and bondage, to one of morality, knowledge, and freedom, than to imagine that by his own fault he has fallen from a condition of god-like elevation and perfection into one of meanness, pullution, and sin, to redeem him out of which his own strength is insufficient.

Nothing so fortifies and increases the courage of the individual human being in his struggle for the highest good, as the consciousness that there is such a thing in the world as *real* progress; that intellectual thought is not labor lost; and that all the acquisitions of the past, all the hopes of the future, rest on the possibility of passing on to coming generations an ever-increasing sum of advantages, not only in the way of corporeal inheritance, but much more in the way of intellectual transmission. Wherefore, this theory of descent, although unproved, and in its separate deductions frequently erroneous, is a logical, but much more a moral postulate. Not as a new dogma, but as a light shining on the dark path of groping inquiry, will it bring abundant blessings to mankind.

4. Spectrum Analysis Explained, and its Uses to Science Illustrated.

INTRODUCTORY.

THIS work is founded upon a series of lectures delivered by the author during the winter of 1869, before the "Society for Scientific Lectures," in Cologne. Its object is, on the one hand, to give a clear and familiar representation of the nature and phenomena of spectrum analysis, enabling an educated person not previously familiar with physical science to become acquainted with the newest and most brilliant discovery of this century; and, on the other hand, to show the important position which spectrum analysis has acquired in the pursuit of physics, chemistry, technology, physiology, and astronomy, as well as its adaptability to almost every kind of scientific investigation.

The general reader will be introduced by this book into a new realm of science, the dominion of which has extended in a few years over all terrestrial substances, and even beyond them to the most distant parts of the universe. He will learn to decipher the new language of *light*, which by unequivocal signs yields him information not only concerning the nature of terrestrial substances, but also of the physical constitution of the heavenly bodies.

To facilitate the due appreciation of the results which have been obtained by the application of spectrum analysis to the heavenly bodies, the author has given with each class of objects a summary of the information hitherto furnished by the telescope, and has sought to give a glance in passing at the progressive development and partial transformation of the heavenly bodies.

The author acknowledges with grateful thanks the valuable assistance rendered him by various scientific men who

have kindly communicated to him the results of their labors, among whom he would especially mention Messrs. Huggins, Secchi, Lockyer, Zöllner, Janssen, Morton, and Young.

ON THE ARTIFICIAL SOURCES OF HIGH DEGREES OF HEAT AND LIGHT.

The total eclipse of the sun in India of the 18th of August, 1868, was an event which, it will be remembered, excited extreme interest in the scientific world, and led to a large expenditure of money and labor, in order that a new method of investigation — spectrum analysis — might be applied to those mysterious phenomena invariably present at a total solar eclipse, the nature and character of which the unassisted powers of the telescope had proved themselves inadequate to reveal. The brilliant results obtained at this eclipse were fully confirmed by the more recent observations made in North America during the total eclipse of the 7th of August, 1869, and the records of those eclipses laid before the various scientific societies clearly assert the triumph of spectrum analysis. On this account, the new method of investigation has excited great interest in all cultivated circles, and therefore a familiar and comprehensive exposition of the details of spectrum analysis, in which is shown the great value of this method of research in every department of physical science, seems not uncalled for.

By *spectrum* is not understood in physics a spectre or ghostly apparition, as the verbal interpretation of the word might well lead one to suppose, but that beautiful image, brilliant with all the colors of the rainbow, which is obtained when the light of the sun, or any other brilliant object, is allowed to pass through a triangular piece of glass — a prism.

The unassisted eye can perceive no difference in the light from the heavenly bodies and that from various artificial sources, beyond a variation in color and brilliancy; but it is

quite otherwise when the light is viewed through a prism. There are then formed very beautiful colored images or spectra, the constitution and appearance of which depend upon the nature of the substance emitting the light. The different appearances presented by these colored images are so entirely characteristic, that to every substance, when luminous in a gaseous form, there corresponds a peculiar spectrum, which belongs only to that particular substance.

It follows, therefore, that when the spectra of different substances have been determined once for all, by previous researches, and have been recorded in maps or impressed upon the memory, it is easy in any future investigation to recognize at once, from the form of the spectrum which a body of unknown constitution presents, the individual substances of which it is composed.

This statement presents in general terms the nature of spectrum analysis. It *analyzes* bodies into their constituent parts, not as the chemist, with alembics and retorts, with re-agents and precipitates, but by means of the spectra which these substances give when in a state of intense luminosity.

Spectrum analysis in no way supplants the methods of chemical analysis hitherto in use; for its function is neither to decompose nor to combine bodies, but rather to reconnoitre an unknown territory, and to stand sentinel, and signalize to the physicist, the chemist, and the astronomer, the presence of any substance brought beneath its scrutiny.

With what acuteness, with what delicacy does spectrum analysis accomplish this task! When the balance, the microscope, and every other means of research at the command of the physicist and the chemist utterly fail, one look in the spectroscope is sufficient, in most cases, to reveal the presence of a substance. If a pound of common salt be divided into 500,000 equal parts, the weight of one of these portions is called a milligramme. The chemist is able, by the use of the most delicate scales and the application of special skill,

to determine the weight of such a particle; but in doing so, he comes close upon the limits of his power of detecting by chemical means the presence of sodium, the chief element in common salt. But if that small milligramme be subdivided into three million parts, we arrive at so minute a particle that all power of discerning it fails, and yet even this excessively small quantity is sufficient to be recognized with certainty in a spectroscope. We have but to strike together the pages of an old dusty book in order to perceive immediately in a spectroscope placed at some distance, the flash of a line of yellow light which we shall presently learn is an unfailing sign of the presence of sodium.

It was to be expected that so sensitive a means of investigation, from which no known substance can escape, would very soon lead to the tracking out and discovery of new elements which, till then, had remained unknown, either because they are scattered very sparingly in nature, or stand out with so little that is characteristic, from some other substances, that the imperfect chemical methods hitherto in use have not been able to distinguish them.

This expectation was brilliantly realized even by the first steps taken in this direction. The two Heidelberg professors, Bunsen and Kirchhoff, to whom we are indebted for the discovery of spectrum analysis and its application to practical science, very soon discovered with their new instrument, two new metals, Cæsium and Rubidium, to which two others, Thallium and Indium, have been since added.

But all the brilliant and astounding results which spectrum analysis has furnished in the provinces of physics and chemistry have been far surpassed by its performances in that of astronomy. Newton's law of gravitation has given us the means of calculating the courses of the heavenly bodies, of projecting the orbits of the earth, the planets and comets, and of predicting their relative positions in these orbits, together with the accompanying phenomena of the ebb and flow of the tides, and the eclipses and occultations of the

heavenly bodies. But this same gravitation chains man to the earth, and forbids him to leave it. It is therefore only on the wings of light, that news reaches him of the existence of those numberless worlds by which he is surrounded. The light alone, which proceeds from these stars, is the winged messenger which can bring him information of their being and nature; spectrum analysis has made this light into a ladder on which the human mind can rise billions and billions of miles, far into immeasurable space, in order to investigate the chemical constitution of the stars, and study their physical conditions.

Until within a few years, the telescope was the only means by which these investigations could be carried on, and the intelligence derived from this source concerning the stars and nebulæ was very scant, being confined to but partial information of their outward form, size, and color.

Since the year 1859, spectrum analysis has entered the service of astronomy, and its performances for the short space of eleven years are, in the most widely-differing ways, *perfectly astounding*.

It is possible by means of a prism to decompose into its component parts the light of the sun, the planets, the fixed stars, comets and nebulæ, and thus obtain their spectra in the same way as that of earthly luminous substances. By a careful comparison of the spectra of the stars with the well-known spectra of terrestrial substances, it can be determined, from their complete agreement or disagreement, with a certainty almost amounting to mathematical precision, whether these substances do or do not exist in those remote heavenly bodies.

The foregoing statements present, in general terms, the essence and scope of spectrum analysis. Its starting-point is the spectrum of each individual substance, and in order to obtain this it is requisite that the substance should not only be luminous, but should emit a *sufficient quantity* of light. Dark bodies are not available for spectrum analysis;

if they are to be submitted to its scrutiny, they must first be brought into a state of vivid luminosity.

That the nature of the analysis of light may be more easily understood, we will first proceed to explain

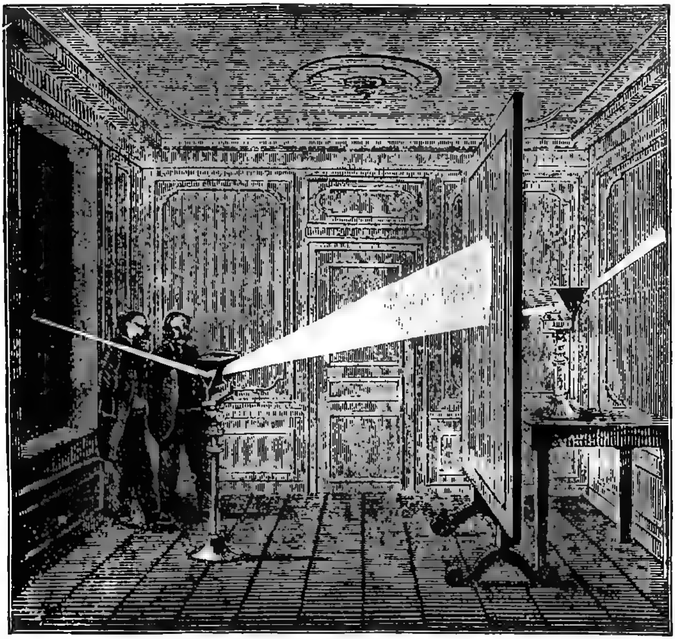
THE SOLAR SPECTRUM.

If a ray of sunshine be allowed to pass through a small, round hole in the window-shutter of a darkened room, as is shown in Fig. I., there will appear a round, white spot of light exactly in the direction of the ray, upon a screen placed opposite the opening, as will be seen indicated by the dotted lines in the figure. A very different appearance will be presented if the ray of light be made to fall upon a prism. The ray is at once deflected from its straight course upwards, that is to say, towards the base of the prism, and away from the sharp edge of the refracting surfaces, which, as represented in the drawing, are turned downwards: on its emergence from the prism it no longer remains one single ray, as it entered the window-shutter, but is separated into very many single-colored rays, which, as they continue to diverge, form upon the screen an elongated band of brilliant colors, instead of the former round, white image of the sun. In this brilliant band the individual colors blend gradually one into the other, beginning at that end lying nearest the direction of the incident ray (the lowest end in the figure), with the least refrangible color, a dark and very beautiful red; this passes imperceptibly into orange, and orange again into bright yellow; a pure green succeeds, which is shaded off into a brilliant blue, and this gives place to a rich, deep indigo; a delicate purple leads finally to a soft violet, by which the range of the visible rays is terminated. A faint picture of this magnificent solar image is given in No. 1 of the Frontispiece; this is called the *spectrum*. In the abovementioned colors of the solar spectrum, the eye discerns numberless gradations, which pass imperceptibly from one

to another; and since language does not suffice to give separate names to each of these, we must content ourselves with designating only the seven principal groups, which are known as the colors of the spectrum.

This experiment furnishes conclusive evidence that white

FIG. I.



EXHIBITION OF THE SOLAR SPECTRUM.

light is not simple and indivisible, but composed of innumerable colored rays, each of which possesses its own peculiar degree of refrangibility, and therefore, on refraction, pursues a separate path. The prism analyzes white light; the result is the separation of all the colored rays of which

it is composed, and the consequent formation of the colored image called the *spectrum*.

The decomposition of sunlight by refraction is shown in various phenomena known to the ancients as well as ourselves, though they were not able, as we are, to trace them back to their true cause. The rainbow, with its pure but delicate colors, the sparkle of the cut jewel in its brilliant flashes, the play of color emitted by cut glass, and the prismatic facets of crystal lustres as the sun shines upon them, the glow of the clouds and high mountain peaks in the various colored light of the rising and setting sun, — all these effects are occasioned by the decomposition of white light by its refraction on passing through glass in a prismatic form, through drops of liquid, or through vapor.

The colors of the solar spectrum possess a purity and brilliancy to be met with nowhere else; they are all perfectly indivisible, and cannot be further decomposed, as may be easily proved on attempting to analyze a colored ray by means of a second prism. If a small, round hole be made in the screen in any portion of the image of the spectrum, — the extreme red, for instance (Fig. I.), — a red ray passes through it, and appears upon the opposite wall as a round spot of red light, precisely in the same direction as the red rays left the prism on the other side of the screen. If a second prism be interposed in the path of the ray that has passed through the screen, the ray will suffer a second refraction, and the image be thrown upon another place (higher up in the figure) on the wall; this new image, however, is simply red, like the incident ray, and by a careful adjustment of the prism shows no elongation, but appears perfectly round.

This decomposition of sunlight, or white light, as it is usually termed, is called dispersion, and is caused by refraction, by which is meant the deviation of a ray of light from a straight line when it strikes any transparent substance (as, for instance, glass or water) obliquely. Different colors are

said to have different degrees of refrangibility; and by this we mean, that different colored rays of light, being passed through a triangular piece of glass, or prism, are turned more or less from the direction in which they entered it. Thus the colors of the rainbow have each a different degree of refrangibility, from red, which has the least, to violet, which has the greatest; and when white light, which is composed of all these colors combined, is analyzed, or separated, these colors are refracted, or turned at different angles, so as to separate, though each is beautifully blended with the one next it. The same is true of light from any source. It is only necessary that any substance should be made sufficiently luminous, to become thoroughly sifted, or analyzed, by means of the spectroscope.

We will now proceed to explain how all substances, such as gases, metals, earths, etc., may be made sufficiently luminous to be made available for spectrum analyses. It is necessary to have sufficient heat to volatilize or turn into vapor any substance to be analyzed. For this purpose many ingenious contrivances have been invented, one of which was invented by Bunsen, one of the discoverers of spectrum analysis. This is called the Bunsen burner, and consists of a gas burner, arranged with a chamber beneath it, where atmospheric air is mixed with the gas before passing up the tube to feed the burner. The flame from this burner is non-luminous, but its heat is intense, and may be made much greater if the atmospheric air, instead of being left to mix itself with the gas, be forced in by means of a powerful blowpipe.

In the Bunsen burner, the combustion of coal gas ensues slowly and incompletely; slowly, because the hydrogen in combination with carbon is supplied only in small quantities; incompletely, because the gases are not mixed in due proportions, and the nitrogen of the air presents a hinderance. If, on the contrary, pure hydrogen gas be previously mixed with as much pure oxygen as will insure its complete com-

bustion (two volumes of hydrogen with one of oxygen), oxyhydrogen gas is obtained, which, when ignited, explodes with a fearful noise, and occasions sometimes the destruction of the strongest vessels. The heat evolved by this combustion is the greatest which can at present be produced by *chemical* means, and it is sufficient to accomplish the fusion of substances which have borne unchanged the action of the hottest furnaces.

In order to make the oxyhydrogen flame a source of intense light, a cylinder of well-burnt lime is placed upon the socket of the lamp, and the flame directed against the upper part. It begins at once to glow, and soon throws out a dazzling, incandescent, or white-heat light. This is called the oxyhydrogen or Drummond's lime-light.

The Electric Spark.

To attain, however, the greatest amount of heat and light which can at present be produced, we must leave the province of chemistry, with its processes of combustion, and turn to that of electricity, where we are encountered by a host of phenomena, accompanied by an intense degree of light and heat.

Besides the well-known machines which excite electricity through the friction of a glass disk, there has been added of late a contrivance called an induction machine, which yields a rich supply of electric force, and gives a spark of intense brilliancy. In all electrical motors arranged for exhibiting light, sparks are formed between two metallic poles or pieces of wire, which are placed in contact with those parts of the machine which collect the positive and negative electricity. By the mutual attraction of the two electricities, and the struggle for union, there ensues a tension of electricity at the end of the metal poles when they are separated from each other; if this be so strong that the obstacle presented by the stratum of air between the metallic conductors is overcome

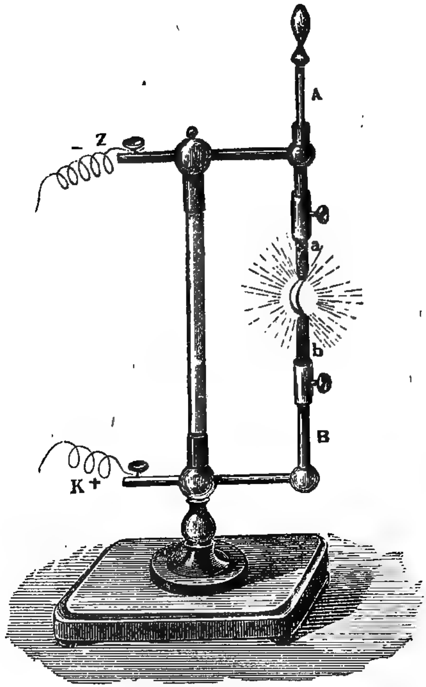
by it, then the electricities are instantly united, and the union takes place in that form of light and heat which is called the *electric spark*.

The amount of heat thus generated depends upon the degree of tension and the quantities of electricity by the union of which it is produced; but in most cases it is so great that small particles of the metal poles are volatilized, and become luminous. The glowing metallic vapor affects the color of the spark, which therefore appears with various kinds of light, according to the nature of the conductors. These phenomena afford us, in aid of our researches with spectrum analysis, a very simple method of volatilizing and raising to a high degree of luminosity most of the metals, and other substances which are conductors of electricity. To obtain the same result with liquids, it is only necessary to place one of the metal poles in the liquid to be examined, and to bring the other sufficiently near the surface for the spark to pass from it to the liquid. By the heat of the spark a small portion of the liquid is volatilized and made luminous.

THE VOLTAIC ARC.

It will be well now to turn our attention for a short time to that source of electricity which is able to evolve the highest degree of heat with the most intense light — namely, the voltaic arc, or the electric light. When the poles of a powerful voltaic battery of fifty or sixty elements are connected, by means of two metal wires, with two pieces of carbon, *a*, *b* (Fig. II.), and these brought into contact, the electricity generated by the battery is discharged between them through the carbon, which is nearly as good a conductor as the metal. If these pieces of carbon be pointed at the ends, an extraordinarily intense light is emitted on the passage of the current at the points of contact, and they may be separated one or two tenths of an inch without interrupting the discharge. The apparatus is then placed in the lantern,

FIG. II.



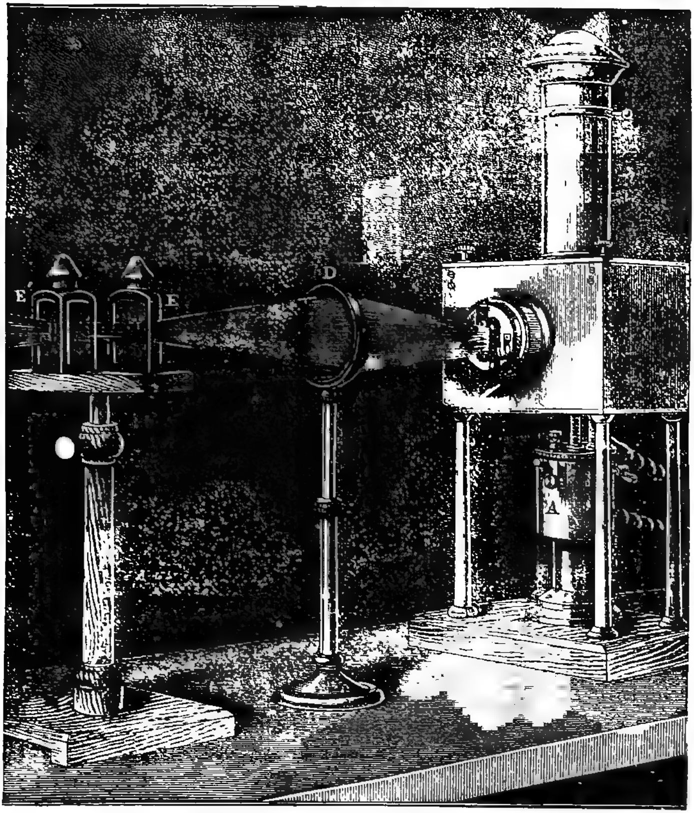
THE ELECTRIC LIGHT.

which is provided with requisite arrangements to keep the carbon points at a proper distance from each other, and also with a small mirror and lens to project the light through a slit in the lantern. The complete arrangement is called

THE ELECTRIC LAMP.

To exhibit the spectrum, the room should be darkened, and the electric lamp placed on a table, with the wires connected with a battery. (See Fig. III.) The light from the

FIG. III.



THE ELECTRIC LAMP.

carbon points passes through the narrow, vertical slit in the lamp, and by means of the movable lens, D, a distinct image of the slit is thrown through the prisms E E upon a screen at a distance of about twelve feet, and we behold a magnificent spectrum, about three feet long and sixteen inches wide, exhibiting the whole range of colors, as shown in No. 1 of

the Frontispiece, with this difference. In No. 1, Frontispiece, the colors are crossed with dark lines, this being a feature of the Solar Spectrum which will be explained farther on. The colors from the *incandescent* or white-hot carbon points succeed each other without the slightest interruption. Their limits are not sharply defined; they rather blend gradually one into the other, and thus form an unbroken or *continuous* spectrum.

RECOMBINATION OF THE COLORS OF THE SPECTRUM.

If white light be actually composed of the colors contained in the spectrum, then the recombination of the same colors must reproduce white light. The simplest method of collecting several rays of light into one point is by a convex lens or a burning-glass. If the sun's rays fall perpendicularly on such a glass, the refraction they suffer in their passage through it causes them to converge to one point—the focus. To accomplish by this means the recombination of the colored rays of the spectrum of the electric light, a cylindrical lens must be interposed between the prism and the screen on which the spectrum of the small line of light issuing from the slit is extended to a length of some six feet: this lens is a convex lens of peculiar form, which possesses the property of recombining in a point all the rays issuing from each point of the line of light passing through the slit after dispersion by the prism, and therefore of representing the whole of the rays of that short line of light again as a small line. When, therefore, this lens is placed at a proper distance behind the prism, the colors of the spectrum disappear from the screen, and are replaced by a short line of light, in which all the colored rays issuing from the prism have been recombined, and the white light reproduced out of which they originated.

THE CONTINUOUS SPECTRA OF SOLID AND LIQUID BODIES.

When the carbon points used for the production of the electric light are carefully prepared, and completely free from all extraneous substances, the light is purely white, being emitted exclusively by solid particles of carbon in a state of incandescence. The spectrum of this light is, therefore, continuous, like that of incandescent lime; it is unbroken by gaps in the colors, or by sudden transitions from one color to another, and is uninterrupted by either dark or bright bands.

All other *incandescent* bodies, whether solid or liquid, give a similar spectrum, the colors being distributed in the order represented in the Frontispiece, No. 1. If, instead of the lime-light, the magnesium light, the light of an incandescent platinum wire, or the flame of coal gas in which light is produced by incandescent particles of carbon, be analyzed by the prism, continuous spectra are always obtained, but with this difference, that the various groups of color are not always distributed in exactly the same proportion in each individual spectrum; and therefore, according to the kind of light employed, sometimes red, sometimes yellow, and sometimes violet predominates. Therefore, where there is *a continuous spectrum without gaps, and containing every shade of color, the light is derived from an incandescent solid or liquid body.*

THE SPECTRA OF VAPORS AND GASES.

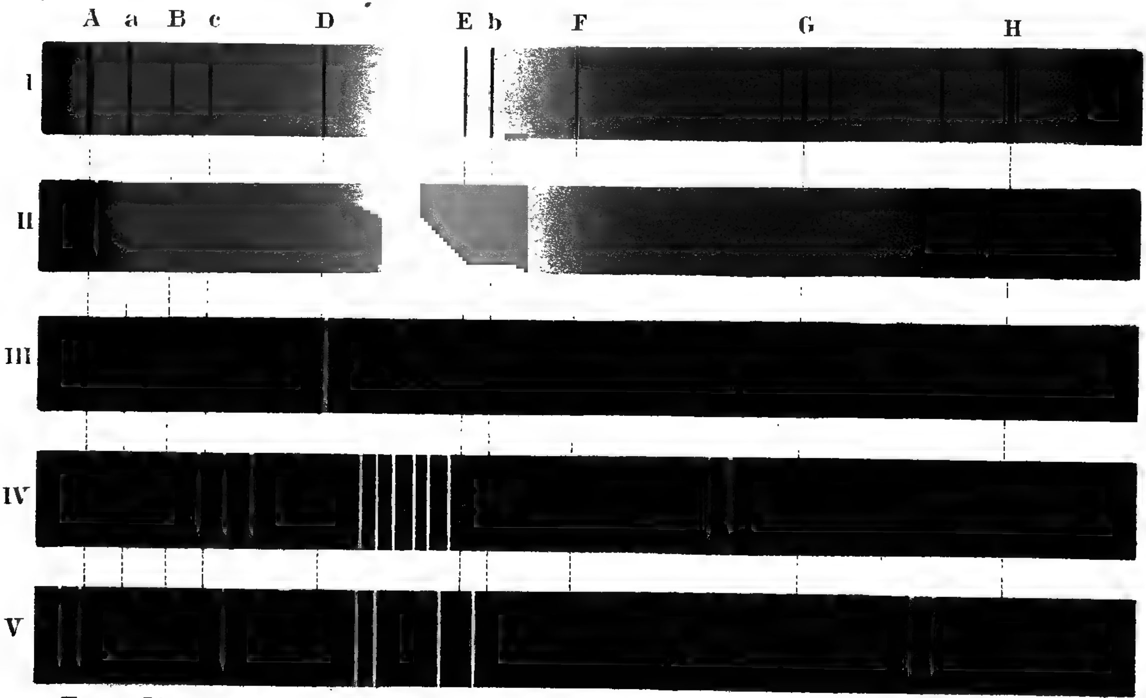
Very different spectra are obtained when the source of light is not an incandescent *solid* or *liquid* body, but a *vapor* or a *gas* in a glowing state. Instead of a continuous succession of colors, the spectrum then exhibits a series of distinct bright-colored bands, separated one from another by dark spaces.

The characteristic feature of spectra obtained from luminous vapors or gases is the want of continuity in the succession of the colors. Such a spectrum is composed of distinct colored bands, irregularly arranged, with dark spaces between them, and is therefore called a *discontinuous spectrum*, a *spectrum of bright lines*, or a *gas spectrum.*

The spectra of the vapors of potassium, sodium, cæsium, and rubidium are represented in Nos. 2, 3, 4, and 5 of the Frontispiece.

The colored plate at the beginning shows certain spectra, observed by means of the spectroscope. It contains five specimens of discontinuous or gas spectrums. Fig. I. represents the solar spectrum, which is, as we showed before, simple white light, or sunlight analyzed into its constituent parts. Fig. II. shows the spectrum of potassium. It is continuous, with the exception of the line in the extreme red, and another in the extreme violet, and without these two lines, would show the spectrum of an incandescent solid or liquid body, or, in other words, a body raised to the point of white heat. Fig. III. shows the spectrum of sodium or salt. This spectrum contains neither red, orange, green, blue, nor violet. It is marked by a very brilliant yellow ray. Of all metals, sodium is that which possesses the greatest spectral sensibility. In fact, it has been ascertained that *one two-hundred millionth of a grain of salt* is enough to cause the appearance of the yellow line of sodium. A very little dust scattered in the room is enough to produce it: a circumstance which shows how abundantly sodium is scattered throughout nature. Kirchhoff has also ascertained that it exists in the sun and the fixed stars.

Figures IV. and V. show the spectra of *cæsium* and rubidium, metals discovered by Bunsen and Kirchhoff, by means of Spectrum Analysis. The former is distinguished by two blue lines, the latter by two brilliant red lines, and two less intense violet lines.



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J G TOMPSON LITH 257 WASHN ST BOSTON

Two other metals, *thallium* and *indium*, have lately been discovered by other scientists by the same means.

Terrestrial substances must be volatilized, or made into vapor, to be examined. The spectra of incandescent *solid* and *liquid* bodies are *continuous*, and resemble each other so closely, that only in a very few instances can they be distinguished; spectra of this kind are, therefore, not suitable for the recognition of a substance, though they authorize the conclusion, as a rule, that the substance is either in a solid or liquid state. Only the discontinuous spectra, consisting of colored lines which are obtained from a gas or vapor, are sufficiently characteristic to enable the observer to pronounce with certainty, by the number, position, and relative brightness of these lines, the chemical constitution of the vapors by which the light has been emitted. It follows from this circumstance that spectrum analysis deals pre-eminently with the investigation of *gas spectra*, and that for the examination of a substance which does not exist in nature in the form of gas or vapor, the first step must be to place it in this condition. We explained how this is done by the use of the Electric Lamp and the Drummond Lime-light.

LIGHT.

Although the theory of light is now so completely understood that we are able to explain the most complicated optical phenomena, yet an elementary reply to the question, What is the nature of light? still presents some difficulty. We perceive the operation of this power of nature in all directions, and in the most manifold ways; the sun, as it stands in full splendor in the heavens, pours forth but a single tone of color over the earth, and yet the individual objects in the landscape appear in the most varied and glorious tints. What then are these colors? How are they developed out of the white light which the sun and other luminous bodies emit?

We need not seek to avoid answering this question, if we can succeed in giving a clear insight into the phenomena of spectrum analysis; for we have already intimated that the world of color is the peculiar province of this new method of investigation.

The approaches to science are frequently obstructed by strange propositions, discouraging and apparently contradictory, which seem to the uninitiated like those ghosts that haunted the way by which Dante and his heavenly guide descended to the realms of the departed; with a little courage, however, we may easily traverse this dreaded path, seize hold of the harmless apparitions, and make friends first with one and then with another as we approach them.

We will therefore boldly grasp the proposed inquiry; if the answer to it cannot be exhaustive, it will at least contain material enough to incite to further reflection, and perhaps also afford the necessary basis for a more easy comprehension of the elaborate theories which are enunciated in physical treatises.

According to the theory generally received at present, the whole universe is an immeasurable sea of highly attenuated matter, imperceptible to the senses, in which the heavenly bodies move with scarcely any impediment. This fluid, which is called *ether*, fills the whole of space — fills the intervals between the heavenly bodies, as well as the pores or interstices between the atoms of a substance. The smallest particles of this subtle matter are in constant vibratory motion; when this motion is communicated to the retina of the eye, it produces, if the impression upon the nerves be sufficiently strong, a sensation which we call *light*.

Every substance, therefore, which sets the ether in powerful vibration, is luminous; strong vibrations are perceived as intense light, and weak vibrations as faint light, but both of them proceed from the luminous object at the extraordinary speed of 186,000 miles in a second, and they necessa-

rily diminish in strength in proportion as they spread themselves over a greater space.

Light is not therefore a separate substance, but only the vibration of a substance, which, according to its various forms of motion, generates light, heat, or electricity.

ANALOGY BETWEEN LIGHT AND SOUND.

This representation of the nature of light ceases to be surprising when we come to compare the vibrations of ether with those of atmospheric air, and draw a parallel between light and sound — between the eye and the ear.

A string set in vibration causes a compression and rarefaction of the surrounding air; in front of it the air is pushed together and condensed; behind it the vacuum it creates is filled up by the surrounding air, which thus becomes rarefied for the moment. This periodic movement of the air is transmitted to our ears at the rate of about 1,100 feet in a second; it strikes against the tympanum, and occasions, by its further impulse on the auditory nerves and brain, the sensation we call *sound.* Air in motion, by its influence on the organs of hearing, is the cause of sound; ether in motion, by its influence on the organs of sight, is the cause of light. Without air, or some other medium whereby the vibration of bodies can be propagated to our ears, no sound is possible. As a sonorous body throws off no actual substance of sound, but only occasions a vibration of the air, *so a luminous body sends out no substance of light, but only gives an impulse to the ether, and sets it in vibration.*

A musical sound, in contradistinction to mere noise, is produced only when the impulses of the air reach the ear at regular intervals; if the intervals between the impulses are not sufficiently regular, the ear is only conscious of a hissing, a rushing, or a humming noise; a musical sound requires perfect regularity in the succession of impulses.

The pitch of a musical note depends on the number of

impulses in a given time — as, for instance, in a second; the greater the number of vibrations in a second, the higher will be the note produced. When the single impulses are fewer than sixteen or more than forty thousand in a second, the ear is no longer sensible of a musical sound: in the first case, it either perceives only an undefined, deep hum, or else it distinguishes the individual strokes upon the tympanum, and becomes sensible of them as distinct blows; in the latter case, there is an impression of a sharp, but equally indefinite shrill or hissing noise. The limits of susceptibility of the ear for musical sounds lie between sixteen and forty thousand impulses per second. The number of vibrations in a second given by a normal tuning-fork was determined in the year 1859 to be 435 in a temperature of 15° C. (59° F.)*

The truth of the foregoing statements may be easily proved in the following manner. A disk of zinc is fastened to an axis which can be set in rapid rotation by means of a cord working over a large wheel. The disk is perforated with eight series of holes, placed along eight concentric circles; the holes are of the same size in each circle, and at equal distances from each other, so that their number increases in each ring from the centre to the edge.

When the disk, by means of the large wheel, is set in uniform motion at the rate of one revolution in a second, and one circle of the holes is blown upon with considerable force through a glass or metal tube, a note is heard: by blowing upon the next series higher, the note is of a higher pitch; a lower set of holes gives, on the contrary, a deeper note; so that if all the rings were blown upon in succession, from the

* [The number of vibrations of a C tuning-fork is 512. The deepest tone of orchestral instruments is the E of the double bass, with 41¼ vibrations. Some organs go as low as C′ with 33 vibrations, and some pianos may reach A with 27½ vibrations. In height the piano-forte reaches to a^{iv} with 3·520. The highest note of orchestra is probably d^{v} of the piccolo flute with 4·752 vibrations.]

lowest upwards, the distinct notes of the complete octave would be heard.

What is it that here produces the sound? The mere revolution of the disk makes no noise; the motion of the air by the blowing through the tube first elicits the notes. When, by the rotation of the disk, the current of air strikes against an opening, it presses through it, pushing the air before it and condensing it; this impulse reaches the ear at once, and strikes upon the tympanum: the current of air immediately afterwards comes against the solid part between the holes, by which it is interrupted. If the circle blown upon contain twenty-four openings, the ear would receive twenty-four impulses at every revolution of the disk; and if the disk made twenty revolutions in a second, the ear would receive $20 \times 24 = 480$ impulses in the same interval. The outside circle has twice as many openings as the innermost one; it therefore furnishes with the same speed of rotation $20 \times 48 = 960$ impulses in a second.

The ear cannot distinguish individual impulses when they exceed sixteen in a second; the impressions they then produce become blended together, the one following the other so instantly that the sensation in the ear is that of one continuous impulse or sound.

The *pitch* of a note is thus seen to depend entirely upon the number of successive impulses following each other at the same uniform rate, its *strength* upon the force of the impulse. With a stronger blast, the pitch of the note remains unchanged, but the tone becomes more piercing, while if a ring containing a greater number of holes be blown upon, the pitch rises till in the last circle, with double the number of openings, the octave of the same note is heard that was given by the innermost circle.

It is true that the cause of sound is not the same in all musical instruments; sometimes it is the vibration of strings, or elastic prongs, sometimes stretched membranes, or, again, columns of air confined in tubes which create at regular

periods a condensation and rarefaction of the air; but in every case a note can only be produced by similar impulses recurring at regular intervals, conveyed by the air to the organs of hearing.

Savart exhibited the cause of sound in another way which is not less instructive than the one just described. Instead of the perforated disk, he made use of a wheel provided with six hundred teeth, which could be set in very rapid rotation in the same manner as the disk, and as the wheel revolved, the teeth were allowed to press against the edge of a card. To make this experiment, it is only necessary to substitute a toothed or cog wheel for the perforated disk, and while the wheel is in rapid revolution, to hold a thin card, or a piece of pasteboard against its toothed edge. The card is bent a little by each tooth as it goes by, and springs back to its first position as soon as it is released by the passing of the tooth: the motion of the card is communicated to the surrounding air, and reaches the ear in consequence of the regular revolution of the wheel, in the form of waves of air, or of condensations and rarefactions of the air following each other at regular intervals.

When the wheel is turned slowly, there is heard only a succession of taps, or isolated impulses of the card, distinctly separable one from another, which do not as yet unite to form a musical sound. In proportion, however, as the rapidity of the rotation is increased, the number of impulses increases also, and they unite in the ear to produce musical notes rising continually in pitch. A small recording apparatus, fixed to the axle of the toothed wheel, gives the number of revolutions in a second; if this number be multiplied by six hundred, the number of teeth on the wheel, the result gives the number of condensations of air striking the ear in a second. It is easy by this means to determine the number of vibrations the ear receives in a second from a note of any given pitch, and thus to verify the results obtained by the perforated disk.

It will now be easier to understand the motion of ether, and its mode of operation on the organs of sight. Ether, as well as air, can be set in regular vibrations, and even in such a manner that the phases of condensation and rarefaction are repeated at regular periods of time. The difference between the vibrations of the air and the ether is occasioned by the remarkable delicacy and elasticity of the latter, which not only permits a greater rapidity in the propagation of motion than is possible with the coarse and heavy particles of air, but also allows the number of vibrations per second to be immensely greater, so that their number has to be reckoned by billions.

Analogy between Musical Sounds and Colors.

Colors are to the eye what musical tones are to the ear. A certain number of ether impulses in a second against the retina of the eye are necessary to produce the sensation of light: if the number of these waves pass above or below a certain limit, the eye is no longer sensible of them as *light*.

The first sensation of these vibrations on the part of the eye commences at about four hundred and fifty billion impulses in a second, and the eye ceases to perceive them when they have reached double this number, or about eight hundred billion: in the first case, the impression produced is that of dark red; in the latter, of deep violet.

The greater the number of vibrations in any given time, the more rapidly must the single impulses succeed each other; it may be concluded, therefore, that the different colors are only produced by the different degrees of rapidity with which the ether vibrations recur, just as the various notes in music depend upon the rapidity of the succession of vibrations of air. The vibrations which recur most slowly, — amounting, however, to at least four hundred and fifty billion in a second, — give the sensation of red; those recurring more rapidly produce that of yellow; and if the

rapidity with which the impulses succeed each other continue to increase, the sensation becomes in succession green, blue, and violet, with which last color the human eye becomes insensible to the ether motion, which, however, is still very far from having attained its limit of rapidity.

The gradation of the colors from red through yellow, green, and blue, to violet, is to the eye what the gamut is to the ear; and it is therefore not without reason that we speak of the tone and harmony of color. To the physicist the words color and tone are only different modes of expression for similar and closely allied phenomena; they express the perception of regular movements recurring in equal periods of time, — in ether, producing colors; in air, musical sounds; in the former instance, by means of the organs of sight; in the latter, by the organs of hearing, — movements of extreme rapidity in ether, of more moderate speed in air.

But it will be asked what becomes of those vibrations which are above and below the limits of the eye's sensibility to light and color? Do they wander about purposeless and unnoticed? By no means: forces are proved to exist in the rays of the sun, and other intensely luminous bodies, which cannot be perceived by the eye. Those slower vibrations which, though they are reckoned by billions in a second, do not yet amount to four hundred and fifty billion, are made apparent to us in the sensation of heat, which is also the result of oscillatory movement — radiant heat being, like light, propagated without the aid of foreign bodies. Those vibrations, on the other hand, which have a velocity greater than that by which deep violet is produced — at which color the eye's susceptibility to light ceases — reveal themselves by their powerful chemical action; they succeed each other too rapidly for the visual nerves to be any longer conscious of the impulses, but they have the power of working chemical changes, and the decomposition of various substances can be undoubtedly traced to the agency of these invisible rays. An English physicist has succeeded in moderating the ex-

cessive velocity of these vibrations by means of certain substances, and in this way has brought some of the invisible chemical rays within reach of the eye's susceptibility.*

Dove describes, in his own ingenious manner, the course of the vibrations as they produce successively sound, heat, and light, as follows: —

"In the middle of a large, darkened room let us suppose a rod, set in vibration and connected with a contrivance for continually augmenting the speed of its vibrations. I enter the room at the moment when the rod is vibrating four times in a second. Neither eye nor ear tell me of the presence of the rod, only the hand, which feels the strokes when brought within their reach. The vibrations become more rapid, till when they reach the number of thirty-two in a second,† a deep hum strikes my ear. The tone rises continually in pitch, and passes through all the intervening grades up to the highest, the shrillest note; then all sinks again into the former grave-like silence. While full of astonishment at what I have heard, I feel suddenly (by the increased velocity of the vibrating rod) an agreeable warmth, as from a fire, diffusing itself from the spot whence the sound had pro-

* [Fluorescent substances possess this property. The peculiar blue light diffused from a perfectly colorless solution of sulphate of quinine was observed by Sir John Herschel, and the colored light diffused from various vegetable solutions and essential oils was subsequently examined by Sir David Brewster. To Professor Stokes, however, is due the true explanation of these phenomena; he showed that the blue light of the solution of quinine consists of vibrations brought within the limits of the power of the eye which were originally too rapid to be visible. If a fresh infusion of the bark of the horse-chestnut be placed beyond the limits of the visible spectrum of sunlight admitted through a slit into a dark room, it becomes beautifully luminous, in consequence of the power which it possesses to lower the invisible ultra-violet vibrations into light which can affect the eye.]

† That is to say, the tympanum is pressed in sixteen times, and sixteen times withdrawn; therefore sixteen blows are received upon the ear.

ceeded. Still all is dark. The vibrations increase in rapidity, and a faint red light begins to glimmer; it gradually brightens till the rod assumes a vivid red glow, then it turns to yellow, and changes through the whole range of colors up to violet, when all again is swallowed up in night. Thus nature speaks to the different senses in succession; at first, a gentle word, audible only in immediate proximity, then a louder call from an ever-increasing distance, till finally her voice is borne on the wings of light from regions of immeasurable space."

The Colors of Natural Objects.

Besides the colors of the spectrum, which are the simple elements composing white light, there is another class of colors apparent in every substance, which are therefore known as the colors of natural objects. When we see that a picture is formed by covering the canvas with various pigments, and that leaves and flowers are bright with the most beautiful tints, while white cloth becomes red, green, or blue, according to the color of the liquid into which it is dipped, we are easily led to believe that every substance carries in itself its own color, which is peculiar to it alone, and is inherent in the substance. At most, we might admit that light was requisite to render the color visible.

And yet this is not so. Were colors really something inherent in the object, every colored substance would manifestly appear always of the same color, by whatever light it was illuminated. But this, as every one knows, is not the case. The beautiful violet dress, which in daylight appears of the purest color, seems dull and gloomy by gaslight; materials which in daylight are a bright blue, are tinged with green in candle or lamp light. And what if the landscape, or a colored object, be viewed through a tinted glass? All colors then seem changed, without the objects in themselves being altered; if the color of the glass be intense, the

various colors of the objects immediately disappear, and everything seems shaded in the color of the glass. The same thing happens if some common salt be rubbed into the wick of a spirit lamp, and surrounding objects viewed by the yellow light of such a flame; the colors disappear, or lose much of their brilliancy, and everything seems either in mere light and shade, or else of a dull gray.

These facts clearly prove that colors are not inherent in objects, that they have no independent existence, but that they are called forth by some extraneous cause.

On the other hand, these considerations show that there must be something in the objects themselves to help in the formation of color; for they in no way assume the color of the light illuminating them, but appear, as a rule, of quite a different hue.

The *natural* color of an object is that in which it appears when illuminated by the pure white light of the sun, or by daylight; it is called red or blue when it so appears by daylight. Now if an object be illuminated by white light, and yet appear of another color, the cause of the change must be looked for in the influence which the surface of the body exercises on the ether waves constituting white light. The effects of this influence are very different, according to the nature of the coloring matter with which the object is provided; but they may mostly be reduced to one of two cases — either that a portion of the ether motion is entirely stopped, or so considerably diminished in its passage over the ponderable atoms of the substance, as that heat, instead of light, is evolved, — or else that the ether waves are irregularly reflected from the surface of the object, as sometimes occurs with the waves of sound. In the first case, the rays of light are said to be *absorbed;* in the latter, *scattered.*

When the surface of a body has the property of absorbing all the colors of the solar spectrum with the exception of one, — the red, for example, — that body appears red to us by daylight, because this color alone is reflected to the eye.

When, on the contrary, it has the power of absorbing some of the rays, — the red and orange, for instance, — and of reflecting the others, namely, the yellow, green, and blue, the color of the object will then be that produced by the mixture of the unabsorbed — the reflected — colors. Now as white light contains the whole range of colors visible in the spectrum, it can easily be understood why so many different colored objects should be seen in nature with such an infinite variety of tints.*

When all the colors of white light are reflected from an object in the same proportions as they occur in the solar spectrum, the object appears white by daylight, and brilliant in proportion to the *quantity* of light it reflects. In proportion, however, as it reflects *fewer* rays of all kinds, the white loses in intensity; the object appears first gray, then dark, and at last black, when all the rays falling upon it are absorbed, and none reflected.

Those objects are therefore black the surfaces of which are so constituted as to absorb all the colored rays of white light; those are white which reflect all the rays which fall upon the surface; and those are colored which reflect some of the rays and absorb others.

A white object may therefore appear of all colors: if red light falls upon it, it reflects it to the eye, and appears red; in blue light, it appears blue; in green light, green, etc.; whereas a black object always appears black, whatever may be the color of the light by which it is illuminated.

We may here further remark that a colored substance assumes a different tint when illuminated by colored light, and then appears of another than its natural, that is to say, daylight color. Vermilion, for example, when placed in red light, becomes of a more fiery red; in orange or yellow

* [A certain proportion of the light falling upon colored bodies is usually sent back unchanged by superficial reflection, without undergoing the elective absorption to which the color of the substance is due.]

light, it appears orange or yellow, but deeper in tone; green rays impart to it something of their own tint, but as the red substance can reflect only a few of the green rays, it appears pale and dull by their light; it seems still duller and darker in blue light, and with indigo and violet it is almost black.

These phenomena are explained by the supposition that the surfaces of colored bodies possess the property of reflecting the rays of one particular color in far greater proportion than those of the other colors; they do not therefore appear black when illuminated by a light differing from their own natural color. Take, for example, a piece of paper half of which is colored a deep blue and half red: the colored rays other than the blue and red are not all absorbed: it is true that the blue piece reflects the blue rays pre-eminently and in greatest number, as the red part does the red rays, but the red has also the capability of reflecting other rays to a small amount. If the pure yellow light of a spirit flame impregnated with salt be allowed to fall on the paper in a completely dark room, the paper must appear black if the coloring matter reflect only the red and blue rays, because the yellow rays of the burning sodium will be absorbed, and no other light falls upon the paper; but this is not the case. The paper only appears black on the blue part; the red half is still visibly colored, though of a decidedly yellow shade. We therefore conclude that the blue of the paper does not reflect the yellow rays, but that the red has that power in a small degree. Almost all colored objects act like the red paper; they reflect pre-eminently one particular color, namely, that one of which they appear by daylight; but they are able also to reflect in small quantities all other, or at least some other colors, and so they vary in tint according to the kind of light in which they are seen.

The colors of objects are very rarely pure and simple, like those of the spectrum; most of them are composed of several colors, and can be decomposed into their original

elements by a prism. As without prismatic decomposition, we are unable merely from the color of an object to say positively which colors are absorbed and which reflected, so it is equally impossible for us to decide, from the color of a flame, what the composition of its light may be, without investigation. The light of the sun, the lime-light, the magnesium light, the light of coal gas, petroleum, and oil, all appear to us more or less white, and yet the spectra of the various lights differ considerably. It is true they all contain the whole range of the colors of the spectrum, from red to violet; but each color is present in very different proportions. The light from gas, oil, and candles has less blue than that of the sun and the lime-light, and very much less violet. A blue material will therefore reflect less blue by lamp, gas, or candle light than by daylight; the color will not only be flat and dull, but will have a touch of green in it, on account of the preponderance of yellow light. Blue and violet especially receive a green tinge by candle light, in which these colors appear much duller than in daylight; and indeed sometimes, according to the nature of the coloring matter employed, this tint is so decided that in artificial light many kinds of green cannot be distinguished from blue.

ABSORPTION OF LIGHT BY SOLID BODIES.

By the term *absorption* we have already designated that action by which light, in its passage through certain media, or by its reflection from the surfaces of bodies, is weakened, partially retained, or entirely stopped. We found that those substances called black absorbed rays of every color, and reflected no light from their surfaces, and that most substances absorbed with great avidity rays of certain colors, while they were insensitive to others. The cause of this absorption is probably due to the vibrations of the ether being communicated to the ponderable molecular particles of the substance.

Similar phenomena are noticed when light is transmitted through colored glass. When all the objects in a landscape appear red through a red glass, it is because the glass allows only the red rays to pass through, and absorbs every other colored ray: such a glass is transparent only to red light, and is opaque to every other color. But it is rarely the case that colored glass is transparent for one color only; most kinds of glass absorb rays of certain colors, and allow the others to pass through in very different proportions. The naked eye is unable to decide which of the colored rays are transmitted through a colored glass; this can only be accurately determined by analyzing the transmitted light by a spectroscope or simple prism.

If we examine by a spectroscope the transmitted light of the colored glass that we before made use of for obtaining red, green, and blue light, it will at once be seen that the ruby red glass transmits some orange and even some yellow rays, as well as the red, but that it entirely absorbs the green, blue, and violet rays; the cobalt blue glass transmits some violet and green rays, besides the blue, but absorbs all the red rays. If both glasses be laid one over the other, and a gas flame looked at through them, it seems as if scarcely a single ray was transmitted; the red glass absorbing the green, blue, and violet rays, and the blue glass absorbing the red rays, there pass through only traces of such light as has not been entirely absorbed, and this causes the gas flame to appear of a dull yellow. A combination of several glasses, or indeed any single glass which absorbs all the colored rays composing white light, is opaque, that is to say, black; glass of perfect transparency, absorbing absolutely none of the transmitted light, does not exist.

RELATION BETWEEN THE EMISSION AND THE ABSORPTION OF LIGHT.

When it is remembered that solid bodies in a state of incandescence *emit* a much greater body of light than gases emit in a similar condition, and that they are able to *absorb* a much greater quantity of the light falling on them, — in certain circumstances, even the whole of it, — through the transfer of the ether vibrations to their ponderable atoms; when, further, it is remembered that just those substances that *give out heat* with the greatest facility, and in the fullest quantity, are also the most capable of *receiving heat* from without, or *absorbing* it, the thought is suggested that there must be an intimate connection, a certain reciprocity between the power of a body to emit light (emission) and to absorb it (absorption). That the temperature of the substance has an influence on this relation between its emissive and absorptive powers, is proved by the phenomena of the gas spectra of the first, second, and third order, as well as by the variety of absorption spectra exhibited at different temperatures by the same substance. A century ago, the eminent mathematician and physicist, Euler, in his "Theoria lucis et caloris," enunciated the principle that every substance absorbs light of such a wave-length as coincides with the vibrations of its smallest particles. Foucault mentioned in his work on the spectrum of the electric light, published in 1849, that owing to the impurity of the carbon points, the intense yellow sodium line appeared, and was changed into a black line when sunlight was transmitted though the electric arc. Angström gave expression, as early as the year 1853, to the general law that a gas, when luminous, *emits rays of light of the same refrangibility as those which it has power to absorb*, or, in other words, that *the rays which a substance absorbs are precisely those which it emits when made self-luminous.*

But all these facts remained isolated, and there was yet wanting the comprehensive grasp of a general physical law, under which the individual phenomena could be arranged. It was reserved to Kirchhoff to discover this law, and to establish triumphantly its truth, not only by mathematical proof, but also, in many striking instances, by experiment.

In the year 1860, he published his memoir on the relation between the emissive and absorptive powers of bodies for heat, as well as for light, in which occurs the celebrated sentence: "*The relation between the power of emission and the power of absorption of one and the same class of rays, is the same for all bodies at the same temperature*," which will ever be distinguished as announcing one of the most important laws of nature, and which, on account of its extensive influence and universal application, will render immortal the name of its illustrious discoverer.

REVERSAL OF THE SPECTRA OF GASES.

From Kirchhoff's law it follows as a necessary consequence that gases and vapors, in transmitting light, absorb or impair precisely those rays (colors) which they themselves emit, when rendered luminous, while they remain perfectly transparent to all other colored rays. Luminous sodium vapor, for example, gives, under ordinary circumstances, a spectrum of one bright yellow double line; it emits therefore this yellow light only. If the white light of the sun, the electric arc, or the oxyhydrogen lamp be allowed to pass through the vapor of sodium, the vapor will abstract or extinguish from the white light just those yellow rays which it emitted when in a luminous state. While the greater part of these yellow rays are absorbed by the sodium vapor, all the other rays — the red, orange, green, blue, and violet — pass through unimpaired.

The important result of these investigations is, therefore, that the characteristic *bright* lines of sodium, lithium, etc.,

are changed into *dark* lines when the intense white light of incandescent solid or liquid bodies passes through the vapor of these metals. The spectrum of luminous sodium vapor is a bright *yellow* (double) line, the rest of the field in the spectroscope remaining dark;* the spectrum of an incandescent solid or liquid body, after it has passed through sodium vapor at a lower temperature than itself, occupies on the contrary the whole field with its brilliant colors, excepting only that one place in which the *dark* sodium line is found. As therefore the bright lines of gas spectra are converted, in these experiments, into dark lines, while the dark parts of the spectrum are changed into brilliant colors by the continuous spectrum of the white light, the entire gas spectrum seems to be reversed in respect of its illumination: for this reason, the phenomenon has been called, after Kirchhoff, "*the reversal of the spectrum.*"

We can now readily predict what appearance will be presented in the spectroscope, if the light of an incandescent solid or liquid body, before entering the slit of the instrument, pass through a less highly heated atmosphere of any kind of vapor, such as that of sodium, lithium, iron, etc. The incandescent body would have produced a continuous spectrum, if its light had sustained no change on the way; but in the vaporous atmosphere through which its rays must pass, each vapor absorbs just those rays which it would have emitted if luminous, thereby extinguishing these particular colors, and substituting for them dark bands in those places of the continuous spectrum where it would have produced bright lines. The spectroscope shows therefore a continuous spectrum, extending through the whole range of colors, from red to violet, but intersected by dark lines; the sodium line, the two lithium lines, the numerous iron lines, etc., appear on the colored ground of the continuous spectrum as so many *dark* lines.

* See No. 3 of Frontispiece.

Spectra of this kind are evidently *absorption spectra;* they are also called *reversed* or *compound spectra.* If a *complete coincidence* can be established in such a spectrum, by means of either a prism of comparison, or a scale, between the characteristic *bright* lines of the gas spectrum of a certain substance, with the same number of *dark* lines, the conclusion may be admitted that in the absorptive atmosphere which has produced the dark lines, the same substance is contained in a condition of vapor.

THE SOLAR SPECTRUM AND THE FRAUNHOFER LINES.

The most brilliant example of a reversed spectrum, — that is to say, a continuous spectrum, crossed by dark absorption lines, — is afforded by the sun. If an ordinary spectroscope, armed with a telescope of low power, be directed to a bright sky, with a rather wide opening of the slit, a magnificent continuous spectrum will be seen, exhibiting the most beautiful and brilliant colors, without either bright or dark lines. But if the slit be narrowed so as to obtain the purest possible spectrum, and the focus of the telescope be very accurately adjusted, the spectrum, now much fainter, will be seen to be crossed by a number of dark lines and cloudy bands. If, by the use of several prisms, the spectrum be lengthened, and a higher magnifying power employed, these thick lines and bands will become resolved into separate fine lines and groups of lines, which are so sharply defined and so characteristically grouped that, by the help of a scale, they are easily impressed upon the memory, and distinguished one from another.

As early as 1802, these dark lines in the solar spectrum had been observed and described by Wollaston; later, in 1814, they were more carefully examined and mapped by Fraunhofer, of Munich; and later still by Becquerel, Zantedeschi, Matthiessen, Brewster, Gladstone, and others; but their origin and nature remained a mystery, notwithstanding

the acutest reasoning and most painstaking researches of many able physicists, until Kirchhoff made his splendid discovery in 1859.

Fraunhofer was able to distinguish with certainty about six hundred lines; he found also that with the same prism and telescope they always kept the same relative order and position, and were therefore peculiarly adapted to serve as marks for denoting the place of any single set of colored rays, and for determining the refrangibility of any particular color.

To facilitate reference to any of the innumerable colors of the solar spectrum (Frontispiece, No. 1), Fraunhofer, whose drawing is accurately represented in Fig. IV., selected out of the great number he observed *eight* characteristic lines, situated in the most important places of the spectrum, which he designated by the letters A, B, C, D, E, F, G, H; of these lines A and B lie in the red, C in the red near the orange, D in the orange, forming a double line with a high power, E in the yellow, F on the borders of the green and blue, G in the dark blue or indigo, and H in the violet. Besides these lines, there is a noticeable group *a*, of fine lines between A and B, and also a group *b*, consisting of three fine lines, between E and F. It was remarked even by Fraunhofer that the position of the two dark lines in the solar spectrum designated by him D, were coincident with the two bright lines shown by the light of a lamp, now known as the double sodium line. These dark lines of the solar spectrum have been called, after their discoverer, the Fraunhofer lines.

Since Fraunhofer counted in the spectrum more than six hundred dark lines, Brewster has counted two thousand, and others, by causing the refracted rays to pass successively through several prisms (some using as many as nine at one observation), the existence of three thousand lines has been ascertained. These lines have been carefully mapped by Angström and Thalen, and Kirchhoff, who has carefully

studied them, and ascertained wherein they *coincide* with the bright lines of metals known to us, says, "The most striking coincidences between the spectrum lines of terrestrial elements and the dark lines of the solar spectrum are shown in iron, sodium, potassium, calcium, magnesium, manganese, chromium, nickel, and hydrogen; the spectrum lines of these substances not only agree exactly with the dark lines in *position* and *breadth*, but proclaim their relationship to them by a similar degree of intensity. The brighter, for instance, a spectrum line appears, so much the darker will its corresponding line be in the solar spectrum.

Fig. IV. shows the principal Fraunhofer lines, A, B, C, etc., and many intermediate ones. It also shows the coincidence between sixty-five of the bright lines in the spectrum of iron and the same number of dark lines in the solar spectrum, *proving beyond a doubt the existence of iron in the sun.* Other observations prove as conclusively the existence of sodium, potassium, and the other metals which are above mentioned.

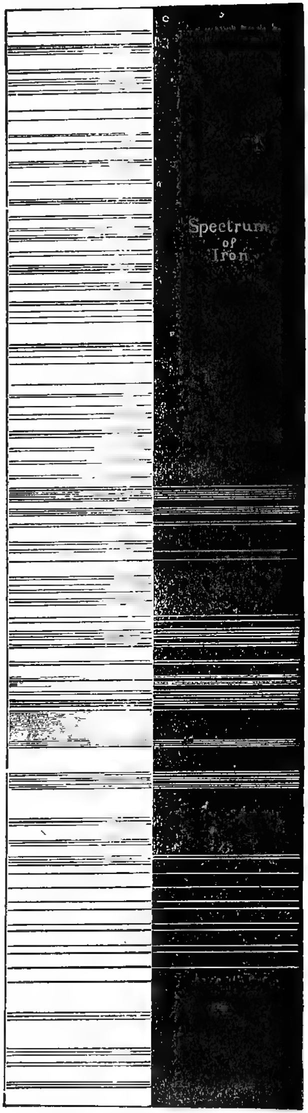


FIG. IV.

THE TELLURIC LINES.

In addition to the Fraunhofer lines, there are other dark lines in the solar spectrum, which are called *atmospheric* or *telluric* lines. These are variable, and are caused by the varying condition of the earth's atmosphere. Janssen found them to be darkest at sunrise and sunset, and less intense in the middle of the day, a periodicity of change which at once proves their atmospheric origin, but they were never entirely absent from the spectrum. He instituted a series of experiments by which he found that a large number of the variable lines in the solar spectrum are due to the presence of *aqueous vapor* in the earth's atmosphere, and also a method secured for detecting the presence of aqueous vapor in the heavenly bodies.

Angström says that nearly all the changes of color observed in the red glow of sunrise and sunset find a simple explanation in the phenomena of atmospheric absorption, whereby all the ingenious and elaborate explanations hitherto attempted are completely set aside.

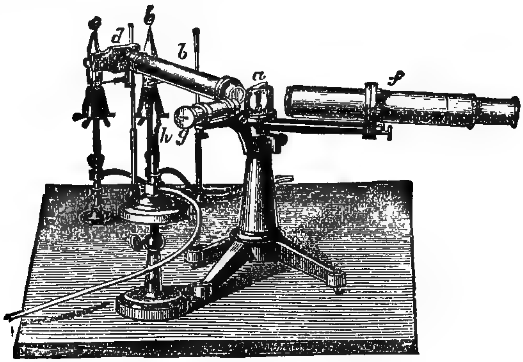
It is fully admitted that other heavenly bodies besides the earth may be surrounded by an atmosphere; Janssen's discovery of the spectrum of aqueous vapor furnishes the means of ascertaining whether this vapor, indispensable to the maintenance of all the living organisms of our planet, is also present in the other celestial bodies. Repeated observations undertaken by Janssen on the high mountains of Italy and Greece have already furnished proof that aqueous vapor is present in the atmospheres of the planets Mars and Saturn.

SPECTRUM APPARATUS.

The thought is perhaps rising in the minds of many who have accompanied us thus far, that the production of the spectrum of a substance for the purposes of analytical examination is encumbered with great difficulties and many troublesome details, involving too much labor to be available

for the use of the chemist and the physicist. This is, however, not the case; if, in our mode of illustration, a powerful galvanic battery, and the electric lamp, with its revolving table and large screen, have been employed, it has been only to show how, by the extraordinary heat and light of the voltaic arc, the simple phenomena on which spectrum analysis is based can be made visible to many hundred spectators at once in a large lecture-room. When, however, the light from the heated vapors need not be greater than is required for a single observer, the whole electric apparatus may be dispensed with, and the simple Bunsen burner substituted; in place of the large screen of paper that reflected the light, the small, sensitive screen of nerves — the retina of the human eye — becomes the surface on which the spectrum is received; and the whole cumbrous contrivance occupying so much space is replaced by a small spectrum apparatus as trustworthy as it is easy to manipulate.

FIG. V.



THE COMPOUND SPECTROSCOPE.

Fig. V. shows a compound spectroscope. With this we are enabled to use two flames, and the apparatus is so arranged that we can see the two spectra, one above the other, and compare them with each other. For instance, putting a small quantity of the substance we know to contain sodium

into one flame, we place a substance supposed to contain sodium in the other flame, and then, by means of a small reflecting prism placed at the end of the slit, we have the spectra of both sent into the telescope, one above the other, and can tell at once whether the lines coincide with each other. Another arrangement for facilitating the comparison of spectra consists of the illuminated millimetre scale contained in the tube *g* (Fig. V.), a magnified reflection of which is thrown into the telescope *f*, from the surface of the prism *a*. The scale is thus seen *between* the two spectra, and the position of any line can be accurately measured, and ascertained.

The reader is now in a position to understand the use of the various parts of a complete spectrum apparatus, especially the three tubes directed to the prism at different angles, as in that constructed by Kirchhoff and Bunsen. The eye of the observer is placed in the axis of the telescope directed to that surface from which the light emerges in the form of a spectrum; the opposite surface of the prism receives through the slit and collimating lens the light emitted from the object to be examined; at the side of the observer is the tube carrying the illuminated scale, or the micrometer screw, so that the mark coinciding with any division of the scale may be placed on any line of the spectrum.

CONCLUSION.

If we have given our readers anything approaching an adequate idea of the beauty and utility of this wonderful discovery, we feel sure it will only stimulate them to investigate and study it further. It was our intention to have continued the subject, and closed this article with a *résumé* of the discoveries made by means of spectrum analysis, but we find it impossible to condense the matter sufficiently to bring it into a size appropriate to these papers, and we defer it to the next number, which will be devoted to *Spectrum Analysis Discoveries.*

5. Spectrum Analysis Discoveries,

Showing its Application in Microscopical Research, and to Discoveries of the Physical Constitution and Movements of

THE HEAVENLY BODIES.

IN the preceding article we gave our readers, in general terms, the scope of this great discovery, and its importance to the scientific world, and, to make it plainer, laid down in a condensed form the received laws of the theory of sound, heat, light, and color, as well as an explanation of the modes in use of detecting minute particles of elements, where all other means had failed. We also showed that, by means of it, many substances, before unknown, had been discovered; and it is not doubted that others will be in the future, as the discovery is still in its infancy.

THE MICROSPECTROSCOPE.

In addition to ordinary spectroscopes, Messrs. Sorby and Browning have devised a combination of the microscope and spectroscope, called the *microspectroscope*, which renders it possible to examine very minute traces of substances. This application of the spectroscope has been very useful in investigating substances which have special importance in physiology and pathology: thus in examining normal and diseased blood, in detecting albumen in urine, and in ascertaining the rate at which certain substances pass into the various fluids of the system, as well as investigating supposed cases of poisoning. The characteristic *absorption bands* which certain liquids, such as wine, beer, etc., present in their normal state, compared with those yielded by adulterated substances, furnish a delicate and certain means of detecting the latter.

An instance of its use in detecting the cause of impurity in water is related, as follows: The water used by the inhabitants of a crowded court, amongst whom several cases of typhoid fever had appeared, was drawn from a rather shallow well, and was highly charged with various unoxidized compounds of nitrogen. It was suspected that, from some defect of drainage, the contents of a public urinal obtained entrance to the well. The fact that the well-water contained seven times as much common salt as the normal water of the vicinity, was some confirmation of the suspicion. Professor Church obtained *absolute proof* of the fact by the following method. He introduced two grammes of a lithium salt into the urinal, and two hours later was enabled readily to detect with the spectroscope the presence of lithium in a litre of the well-water, which by previous examination had shown no traces of this substance. Many other instances of its use for similar purposes might be cited.

Spectrum analysis has thus opened a wide field of investigation to the physiologist, the physician, the botanist, the zoölogist, the chemist, and the technologist, and the labors undertaken in these various departments of science have already yielded valuable results.

It was shown in our last paper that by it we have at last the means of forming a definite idea of the physical constitution of the heavenly bodies, and ascertaining the existence of atmospheres around other planets, and other means of supporting life such as exist on this earth. We will proceed to give a *résumé* of the other discoveries regarding the physical constitution and movements of the heavenly bodies.

KIRCHHOFF'S THEORY OF THE PHYSICAL CONSTITUTION OF THE SUN.

It had long been assumed that the gaps in the colors of the solar spectrum which form the Fraunhofer dark lines, were due to an absorption of the corresponding colored rays

in the atmosphere of the sun; but no explanation could be given of this phenomenon. The cause of this absorption was ascertained by Kirchhoff in his discovery that a vapor absorbs from white light just those rays which it emits when luminous, and he proved the whole system of the Fraunhofer lines to be mainly produced by the overlying of the reversed spectra of such substances as are to be found in the earth. He thus arrived at a new conception of the physical constitution of the sun which is entirely opposed to the theories held by Wilson and Sir William Herschel in explanation of the solar spots.

According to Kirchhoff, the sun consists of a *solid* or *partially liquid* nucleus in the highest state of incandescence, which emits, like all incandescent solid or liquid bodies, every possible kind of light, and therefore would of itself give a *continuous* spectrum without any dark lines. This incandescent central nucleus is surrounded by an *atmosphere* of lower temperature, containing, on account of the extreme heat of the nucleus, the vapors of many of the substances of which this body is composed. The rays of light, therefore, emitted by the nucleus, must pass through this atmosphere before reaching the earth, and each vapor extinguishes from the white light those rays which it would itself emit in a glowing state. Now it is found, when the sun's light is analyzed by a prism, that a multitude of rays are extinguished, and just those rays which would be emitted by the vapors of sodium, iron, calcium, magnesium, etc., were they made self-luminous; consequeutly the vapors of the following substances, sodium, iron, potassium, calcium, barium, magnesium, manganese, titanium, chromium, nickel, cobalt, hydrogen, and probably, also, zinc, copper, and gold, must exist in the solar atmosphere, and these metals, therefore, must also be present to a considerable extent in the body of the sun.

Could the light from the sun's nucleus in any way be set aside, and only that of the incandescent vapors of the sun's

atmosphere be received through the slit of the spectroscope, a spectrum would then be obtained composed of the actual spectra of these substances, that is to say, the same system of bright colored lines which now appear as the dark Fraunhofer lines.

THE SOLAR SPOTS; THE FACULÆ AND THEIR SPECTRA.

It would lead us too far from our subject were we to dwell upon the phenomena of the solar spots, important as they are for acquiring a knowledge of the physical constitution of the sun, or enter upon a full description of their form, their mode of formation and disappearance, their motion, their connection with the sun's rotation upon its axis, their periodic occurrence, and the various hypotheses that have been formed as to their nature; but, on the other hand, we must still less be silent on the subject, since spectrum analysis has investigated these wonderful appearances with a success which has added much to our knowledge of the constitution of the sun.

Fig. 6 shows a remarkable group of solar spots. These, and indeed a large proportion of solar spots, consist principally of a dark, almost black, central portion, the *umbra* * surrounded by a space somewhat less dark called the *penumbra:* the umbra has generally an irregular form, while the penumbra exhibits a structure radiating towards the centre.

If the sun be observed with a high power, the surface presents by no means a uniform appearance; a multitude of bright and dark stripes cross each other in all directions, and

* The dark central part of a spot has been distinguished throughout by the name *umbra*, in accordance with the usual custom of astronomers. Mr. Dawes showed that within this part of a spot one or more darker spots may generally be observed, to which he gave the name of *nucleus.*

4

FIG. VI.

Group of Solar Spots observed and drawn by Nasmyth, 5th June, 1864.

the luminous surface appears like a net of bright meshes interwoven with dark threads and small dark pores. The brightest portions (Fig. 6) show a more or less elongated form, which suggested to Nasmyth the name of "willow leaves," while Dawes compares them to "bits of straw," and Huggins calls them merely "granules."

On this uneven and ever-varying bright background the spots make their appearance in the greatest variety of form and size. The penumbra not unfrequently stretches across the black central portion in various places (see right hand spot, Fig. 6), and generally appears much darker at the outer edges, where the spot touches the bright part of the sun's surface, than in other places. Very often the penumbra is traversed by few or more bright curved bands, stretching from the outer edge towards the nucleus, generally at right angles to the confines of the nucleus and penumbra, which give the spot the appearance as if a number of streams of some luminous matter had broken through the dam formed by the penumbra, to fall into the abyss of the umbra. (See central spot, Fig. 6.) Even the umbra itself is often crossed by one or more broad luminous bands called *bridges*, by which it is divided into several portions.

Besides the dark spots, and chiefly in their immediate neighborhood, bright places make their appearance on the sun's surface, which have been called *faculæ*. They are generally the attendants of solar spots, and are especially to be seen at the extreme edge of the penumbra when the spot has reached the sun's limb, that is, its edge or border; that they are not the effect of contrast between the dark spot and the neighboring brightness, is proved by the circumstance that every spot is not accompanied by faculæ, and that very frequently isolated faculæ are to be seen, which are almost always the precursor of a coming spot.

The faculæ, like the spots, vary considerably in form; generally they are round and concentrated, but often they

have the appearance of long stripes of light, disposed like veins, converging from all sides towards a spot.

The wreathed faculæ are almost always followed in a few days by the appearance of a group of spots; among the vein-like waves of light visible in many places, more especially towards the sun's limb, there is first developed a dull scar-like place out of which the spots are formed, sometimes singly, and sometimes in groups; and not unfrequently the formation of a spot may be predicted from the increased intensity of light at that place on the sun's disk.

When a spot is observed near the sun's limb or edge in the midst of the surrounding faculæ, it is difficult to avoid the impression that the spot lies in a hollow between bright overhanging mountains; and it was observed by Secchi on the 5th of August, 1865, that the faculæ, when they reached the western limb of the sun, appeared like small projections and irregularities upon the sharply defined limb of the sun.

Although the real connection between the faculæ and the spots is not yet fully understood, it may be safely concluded from these observations that the spots lie deeper in the solar surface than do the faculæ, and that these faculæ are mountainous elevations of the luminous matter forming the photosphere, by which the spot is surrounded in a wide circuit as by a wall.

The group of solar spots observed and drawn by Nasmyth on the 5th of June, 1864, is given in Fig. 6, in which all the details characteristic of a spot are to be recognized — the black umbra, the penumbra in a variety of forms, composed of the "leaves" directed towards the umbra, and the surrounding luminous surface of the sun presenting its usual granulated appearance. This surface is called the *photosphere*, a name given without reference to any particular theory as to its physical constitution or structure. The photosphere is entirely covered with *pores*, or small spots, less luminous than the other parts; where they congregate, and become conspicuous by forming a black umbra and shaded

penumbra, they constitute the ordinary *solar spot;* where the portions of greater brilliancy than the surrounding parts of the photosphere congregate, they form the *faculæ*, and these generally accompany the spots, or precede their formation.

If a solar spot be watched in the telescope from day to day, or from hour to hour, it will soon be seen to change in form; it increases or diminishes, or completely vanishes away, while new spots make their appearance. In the process of disappearing, the dark umbra first gradually contracts until it becomes invisible, leaving the dusky penumbra perceptible for some time longer. Not unfrequently a spot breaks up into several spots, and occasionally a group unites to form one, and sometimes, even, one spot is seen to pass over another, partially covering it, and then withdrawing from it. In all these changes, the spots exhibit an amount of mobility displayed in general only by liquid or vaporous masses.

The formation and changes in the configuration of a spot may often be watched during the course of observation, and it not unfrequently happens that the appearance of a group of spots is so entirely changed from one day to another, that it can no longer be recognized in the new form it has assumed.

On the other hand, there are spots presenting scarcely any change, which preserve nearly the same form for many days together. Spots of this kind are of the highest value to the astronomer, as they afford the only means of ascertaining the time of the revolution of the sun upon its axis, the position of this axis, and its inclination to the earth's orbit.

It not unfrequently happens, that the same spot which has been observed to disappear on the western limb has, in the course of about fourteen days, been seen to reappear on the eastern limb, and in the lapse of another fourteen days has disappeared a second time on the western limb — a phenomenon that proves beyond a doubt that the spots are con-

nected with the surface of the sun, and that the sun itself has a revolution upon its axis. If the time required for the earth's motion round the sun be allowed for in this revolution of the spot, the result will show, according to Spörer, a mean time of rotation for the sun amounting to twenty-five days, five hours, thirty-eight minutes.

Kirchhoff considers these forms to be cloud-like condensations in the sun's atmosphere, which are produced by the loss of the solar heat by radiation, in the same way as the aqueous vapors of the earth's atmosphere are formed into mist and cloud. When such clouds arise over the bright and glowing surface of the sun, they obscure the light of the sun at that spot, and it is but natural that these cloudy masses, so irregularly formed, should also become further condensed, or be dispersed with the same amount of irregularity, according as they come in contact with cooler or warmer streams of gas.

The results of the spectrum observations of Secchi, Lockyer, and Young, important and valuable as they are, remain as yet too isolated and unconnected with telescopic observations of the spots and faculæ to yield material sufficient for explaining the nature of these forms. This much, however, may be regarded as certain — that the phenomena of the increase in the width and intensity of the Fraunhofer lines, as well as the appearance of new dark bands in the spectrum of the umbra, *are produced by the increased absorptive power exercised by the substances of which the spot is formed.*

When the white light of the sun's nucleus which has already suffered absorption from the absorptive stratum passes through the vaporous matter of a spot, it undergoes a yet further absorption from the additional matter which the spot contains. As, therefore, the lines of calcium and iron are considerably affected in the spectrum of a spot, the sodium lines in a smaller degree, and to some extent those of magnesium, it may be concluded that the substance forming

the solar spots is composed pre-eminently of vapors of calcium, iron, titanium, sodium, barium, and magnesium, and that these substances occur in layers of varying thickness, and in very different proportions.

That hydrogen gas constitutes an important element in the formation of the spots, is shown in the most unequivocal manner by the spectrum. The hydrogen lines are most affected in the parts that lie close to the umbra, in the bridge, when one is formed, and in the penumbra.

An explanation of this phenomenon is, that hydrogen gas breaks forth, from time to time, from the interior of the incandescent solar nucleus. Owing to its extreme lightness, this gas would rise in enormous pillars of flame (prominences) over the absorptive vaporous stratum of the photosphere, and, in consequence of the cooling ensuing from expansion, would enter into a variety of chemical combinations, especially with oxygen; the uncombined part would then flow to the side, while that in combination with oxygen (steam) and the other solar substances would form gaseous or vaporous masses, which, from their nature as well as from their continued cooling, would be heavier than the hydrogen gas, and would sink down from their greater gravity. It is to be expected that the stream of gas on rising would carry up with it a quantity of those substances that exist in the sun's nucleus and the surounding stratum of absorptive vapor (the photosphere); if these substances, themselves incandescent, were present in sufficient quantities in the luminous hydrogén gas, their characteristic lines would be seen as bright lines in the spectrum of the pillars of flame. During the recent total eclipses, many such lines were in fact observed, together with the bright hydrogen lines, in the prominences, a description of which will be given farther on; they can now be observed daily, sometimes in great numbers, upon the sun's disk.

When the force of the gas eruption has somewhat subsided, and the chemical combinations ensue, producing vaporous

precipitations of many kinds, the formation of the spot begins. The heavier portions of these precipitations sink down, and form the *umbra* of a spot at the place of greatest condensation, while the parts which are less dense constitute the *penumbra*. The vaporous umbra, however, though apparently quite black, is yet able to transmit a considerable amount of sunlight; indeed, according to Zöllner's measurements, the black umbra of a spot emits *four thousand times* as much light as that derived from an equal area of the full moon. This statement is fully confirmed by the results of spectrum analysis, for even the blackest umbra yields a spectrum exhibiting all the details of full sunlight.

The various remarkable changes which the lines of hydrogen, magnesium, sodium, calcium, and iron suffer in the spectrum of the umbra, seem to show that in the cloud-like and vaporous substances constituting the spot, the new combinations are disposed in layers, according to their specific gravity. Thus hydrogen gas occupies the highest stratum; aqueous vapor, magnesium, and sodium follow in thinner layers below; and the heavier vapors of calcium, titanium, and iron form the lowest and densest stratum, the base of the spot.

The formation of a spot will accordingly immediately follow an eruption of hydrogen; the spot itself is a dense, cloudy, luminous mass, probably of a semi-fluid consistency, composed of many constituents — according to Zöllner, a kind of scoria — which sinks by its gravity a certain depth into the photosphere, or outer portion of the sun, and partially intercepts the light from the lower stratum of the photosphere, therefore presenting to us the appearance of a dark mass projected upon the disk of the sun, in the same way as the exceedingly intense light of the oxyhydrogen lime-light appears black when seen against the sun.

The enormous dimensions of these dense masses of vapor, which extend sometimes in all directions, account for the length of time the spots continue visible, not unfrequently

remaining during several rotations of the sun. Their disappearance is to be explained partly by the substance of the photosphere flowing into the cavity of the spot, partly by the complete subsidence of the vapors into the nucleus of the sun, where, in consequence of the enormous heat, the compound substances which may exist in them are broken up into their original elements.

These conjectures are by no means intended to afford a complete explanation of all the phenomena of a solar spot. Though it certainly is of the highest interest for us to acquire a knowledge of the physical nature of that heavenly body whence we derive light, heat, motion, and life, we must yet be cautious of receiving for truth what is only the result of speculation, especially as the theories on this subject rest on isolated observations which are too unconnected to point to any certain conclusion. The suggestions here thrown out are only intended, therefore, to throw some light upon the results hitherto obtained by the spectrum observations of Secchi, Huggins, Lockyer, and Young, and by affording an unconstrained interpretation of them to bring them into harmony with the phenomena observed during the total solar eclipses of 1868, 1869, and 1871.

Total Solar Eclipses.

The reason why our knowledge concerning the nature of the sun is still so imperfect, is that the remarkable phenomena occurring on the sun's limb are so completely overpowered by the blinding light of the solar nucleus or photosphere, that they remain invisible even in the most powerful telescopes. It is not sufficient to get rid of the sun's rays by the interposition of an opaque screen, because the diffused light of the sky cannot be eliminated by this means, and this light, even, is so intense as to conceal the faint light of the sun's appendages. It is quite otherwise, however, during a *total eclipse* of the sun; then the moon covers the whole of

the sun's disk, and includes a large tract of the earth's surface in the cone of its shadow, revealing to the observer, who is no longer hindered by the light of day, a display of phenomena round the sun which can be seen in no other way, and the study of which is peculiarly fitted to throw light on the nature and physical constitution of the sun.

We will not suffer ourselves to be detained by a description of those changes that pass over the landscape as the darkness advances, nor dwell upon the deep impression which the sudden disappearance of the last rays of the sun, and the equally sudden reappearance of the light, make both upon men and animals.

The diameter of the cone of the shadow thrown by the moon towards the earth, amounts at the spot where it touches the earth's surface on the equator during the time of totality to about 122 miles: as, however, the moon, which throws the shadow, only completes its course in the heavens round the earth from west to east in one month, and the earth, which receives the shadow, accomplishes its revolution from west to east in one day, it follows that the motion of the moon's shadow is very much slower than that of the earth's surface. It therefore happens that the earth appears to run away from under the moon's shadow, or that the moon's shadow seems to run over the earth from east to west. From an elevated position the shadow of the moon is seen to approach with enormous rapidity, and the sensation as though a material substance, such as a terrific cloud of smoke, were rushing over the earth's surface, fills the uninitiated spectator with fear and dread. A few minutes before the commencement of the totality, the brightest stars become visible, and the sharply defined black edge of the moon appears surrounded on all sides by a very narrow but very brilliant ring of light, of silver whiteness, which is called the *corona*. From the corona faint rays of light, irregular in length and breadth, stream out in all directions, surround-

ing the moon's disk like a glory, whence this crown of rays is usually designated the glory or *halo*.

When the total darkness has commenced, the *prominences* make their appearance, which are cloud-like masses of a rose or pale coral color, disposed either singly or in groups, at various places on the moon's limb.

They pierce the corona in the most wonderful forms, sometimes as single outgrowths of enormous height, sometimes as low projections spreading far along the moon's limb. The prominences are generally first seen on the eastern (left) side of the sun, where at the commencement of the totality the moon only grazes the sun's edge, and the space immediately surrounding the sun is yet uncovered; in proportion as the moon advances to the east, the space immediately surrounding the western parts of the sun becomes free, and the prominences are then seen also on that side in greater number, and developed with much greater distinctness.

There remains now no longer any doubt that these remarkable phenomena belong to the sun, and are great accumulations of the luminous gaseous material by which the solar body is wholly surrounded; it cannot therefore greatly astonish us that their forms have been seen to change even during the short duration of the totality; that which calls much more for wonder is the enormous height to which these pillars of gas extend beyond the limb of the sun, a height which in some instances exceeds ninety thousand miles.

THE TOTAL SOLAR ECLIPSE OF THE 7TH OF AUGUST, 1869.

This eclipse was invisible in Europe; the zone of totality stretched from Alaska, where the eclipse began at noon, over British America and the south-west corner of Minnesota, then crossed the Mississippi near Burlington (Iowa), and passed through Illinois, Western Virginia, and North

Carolina, reaching the Atlantic Ocean in the neighborhood of Beaufort.

The event excited the most lively interest among astronomers and photographers throughout the whole of North America, and occasioned the equipment of a number of scientific expeditions, which were also supplemented by the valuable labors of many private individuals. The observers were in almost every instance favored with the finest weather, and their efforts were rewarded by a large collection of photographic pictures, and many valuable spectroscopic and other observations. That portion of the zone of totality which traversed the inhabited parts of the United States was studied everywhere with telescopes, spectroscopes, and other instruments of observation, so that the whole of this tract of country became one vast observatory. Although the duration of totality was less than in the eclipse observed in India (1868), yet the phenomenon was attended on the whole with many more favorable circumstances; the heat was less intense, the places suitable for observation were much more conveniently situated, and the sun's altitude was not so great as in the eclipse of 1868. The most important points of investigation had reference to the scrutiny of the prominences by means of photography and the spectroscope, the examination of the nature of the corona, and the search for planets between Mercury and the Sun.

The most complete expeditions were those sent out from Washington, one from the Nautical Almanac Office, the astronomical department being under the charge of Professor Coffin, while the photographic arrangements were conducted by Professor Henry Morton, of Philadelphia: another expedition was despatched from the United States Naval Observatory, under the superintendence of Commodore B. F. Sands.

The first expedition, under the guidance of Professor Morton, selected stations in the State of Iowa, as follows: —

1. Burlington, where the observers were Professor Mayer,

and Messrs. Kendall, Willard, Phillipps, and Mahoney, together with Dr. C. A. Young, Professor of Dartmouth College (Hanover), well known as an experienced spectroscopist, and Dr. B. A. Gould, to whose charge the photographic department was committed;

2. Ottumwa, where Professor Himes, and Messrs. Zentmayer, Moelling, Brown, and Baker, were stationed;

3. Mount Pleasant, occupied by Professor Morton, and Messrs. Wilson, Clifford, Cremer, Ranger, and Carbutt, as well as by some other Professors, including Pickering, who were desirous of making astronomical observations on the physical phenomena of the eclipse.

Stations selected by the second expedition: —

1. Des Moines (Iowa), where Professor Newcomb undertook the observation of the corona and the search for intermercurial planets, Professor Harkness the spectroscopic investigations, and Professor Eastman the meteorological department. Several other gentlemen skilled in solar photography associated themselves with these observers.

2. Bristol (Tennessee), where Bardwell, who undertook the observation of the corona, and other observers were stationed.

Besides these most important expeditions, furnished with the most admirable and complete means of observation, several scientific men were engaged at various points in the zone of totality, either in observing the astronomical details of the eclipse, or in investigating the prominences, the corona, and their spectra. Among these may be mentioned Dr. Edward Curtis, who at Des Moines obtained no fewer than one hundred and nineteen pictures of the different phases of the eclipse; W. S. Gilman, by whom some most valuable observations were instituted at St. Paul Junction (Iowa) upon the connection between the solar spots, the faculæ, and the prominences; J. A. Whipple, who with Professor Winlock and several assistants procured at Shelbyville (Kentucky) eighty photographic pictures, six of which were taken

during the totality, one of them exhibiting a complete and magnificent corona; as well as Professor G. W. Hough, Director of the Dudley Observatory, who in company with nine fellow-observers recorded all the details of the eclipse at Mattoon (Illinois).

Out of the mass of materials afforded by the observations of this eclipse, it will only come within our province to communicate those results which have reference to the physical constitution of the sun, and were obtained partly by photographic delineation, and partly by the help of the spectroscope. The course of the eclipse and the photographic work carried on at Mount Pleasant, where the totality lasted two minutes, forty-eight seconds, is described by Wilson nearly as follows: —

"For some days prior to the eclipse, the sky was overcast, and threatened rain; but the 7th of August was bright, without a cloud, such a day as had not occurred for months, and the sun shone with remarkable clearness and warmth. The moment of first contact arrived; the first plate was already placed in the tube; Professor Watson signalled to us the moment for exposure by a motion of the hand; the instantaneous shutter was opened and closed, and the first picture was taken. We thus commenced a series of pictures taken at intervals of five or ten minutes till the commencement of totality, after which the series was continued on the re-appearance of the sun till the termination of the eclipse. Darkness came on with the totality, but not the darkness of night; still it rendered reading impossible. The amount of light upon the landscape was scarcely equal to that of bright moonlight, yet it was sufficient for us to pursue our work. An instant before the commencement of totality, the thin crescent of the sun was still quite dazzling; then the light went out as from an expiring candle.

"There, between heaven and earth, hung face to face the two great luminaries, sun and moon, a large black round spot encircled by a brilliant ring of deep gold-colored light,

interrupted here and there by the brighter spots of the flesh-colored prominences of irregular size and form, and surrounded by the magnificent corona, which shot out rays in every direction, faintest where the prominences were most conspicuous, but enveloping the whole with a glory which was marvellously beautiful, as if the Creator were about to show His omnipotence in this wonder. The phenomenon resembled a gigantic image from a magic lantern, received upon the heavens as a screen. Four plates were exposed, when suddenly the full significance of those words was realized, 'Let there be light, and there was light,' for a mighty flood of brilliant light gushed forth, like the rushing, foaming waters of Niagara. The sun came forth like a conqueror from a battle with the Titans, and was greeted with acclamations by the assembled spectators."

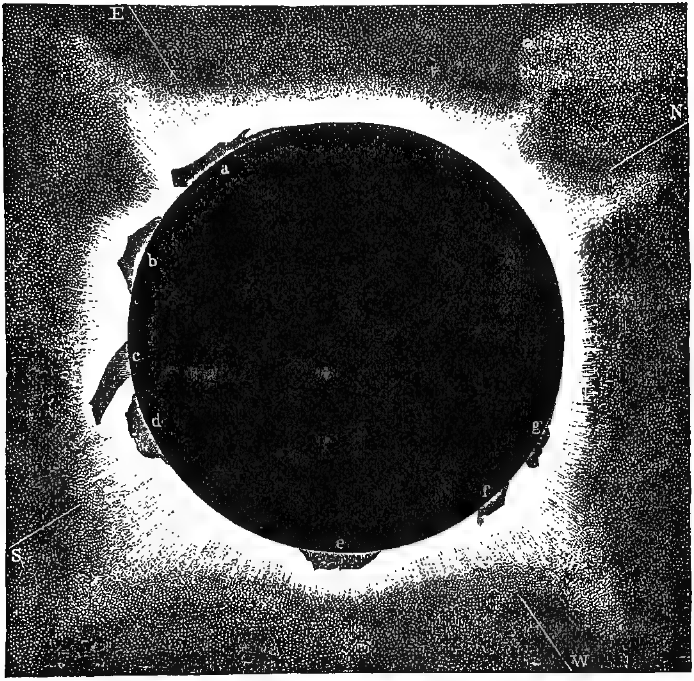
A picture of this magnificent spectacle is given in Fig. VII., showing the prominences and corona after a photograph by Professor Eastman, which was taken at the commencement of the totality. The instant the totality began, the corona made its appearance as a light of silvery whiteness, with an exceedingly tender flush of a greenish-violet hue at the extreme edges, and not the slightest change was perceptible during the totality in the color, the outline, or the position of the rays — an observation confirmed by Professor Hough at Mattoon (Illinois), by Gill, and by several others.

The corona appeared to consist of two principal portions: the inner one, next to the sun, was nearly annular, reaching an elevation of about 1′, and in color of a pure silvery whiteness; the outer portion consisted of rays, some of which grouped themselves into five star-like points, while the others assumed the appearance of radiations, and were the most sharply defined; the corona was scarcely visible between the prominences *a* and *b*. The star-like rays attained a height equal to *half the diameter of the sun.*

The observations made by several astronomers in India during the eclipse of 1868, and those made by many others

in America during that of 1869, and still later those by Lockyer, Janssen, and others in and near the island of Ceylon, in December, 1871, fully justify the conclusion that, independently of the cosmical materials which must exist in the neighborhood of the sun, there exists around this body

FIG. VII.



The Corona of the Eclipse of 7th August. 1869, at Des Moines.

an atmosphere very extensive and excessively rare, with hydrogen for its basis. This atmosphere, which undoubtedly forms the outside gaseous envelope of the sun, is fed by the material of the protuberances projected with such violence from the bowels of the photosphere, but is distin-

guished from the chromosphere and the protuberances by a density enormously less, a lower temperature, and perhaps by the presence of certain different gases.

The prominences are masses of luminous gas, principally luminous hydrogen gas; they envelop the entire surface of the solar body, sometimes in a low stratum extending over exceedingly large tracts of the sun's surface, sometimes in accumulated masses rising at certain localities to a height of more than 80,000 miles.

They are, as respects their first formation, phenomena of eruption. The velocity with which the gaseous matter of the prominences must pass the photosphere must be, in many cases at least, two hundred miles per second, and its initial velocity probably not less than three hundred miles per second. Dense gaseous matter flung out with the hydrogen would probably retain a velocity of, say two hundred and forty miles per second, and reach a height exceeding that indicated by the greatest extension of the radiations observed last December.

The body of the sun, or its light-giving envelope, the photosphere, is completely surrounded by a gaseous envelope, in which hydrogen constitutes the chief element, and which is called the chromosphere. Its mean thickness is between five thousand and seven thousand miles.

The prominences are local accumulations of the *chromosphere*, and therefore pre-eminently of hydrogen gas, which appear to break forth from time to time from the interior of the sun in the form of monster eruptions, forcing their way through the photosphere and chromosphere. As this gas, on effecting a passage, rises with great rapidity, it becomes quickly rarefied in a direction away from the sun's limb.

From the experiments undertaken by Lockyer, Frankland, Wüllner, and Secchi, it appears that *even in the lowest stratum of this gaseous envelope, the pressure is smaller than that of our atmosphere, therefore that the gas of the chromosphere is in a state of greater attenuation.*

Under the chromosphere lies the luminous cloud-like vaporous or nebulous *photosphere*, which contains all the substances, the spectrum lines of which appear as absorption lines in the solar spectrum. These substances — among which iron, magnesium, and sodium are especially prominent — often burst forth in a state of incandescence, and are carried up to a certain distance into the chromosphere, and into the basis of the prominences, though not in general to any considerable elevation.

It is probable that, owing to a continuous decrease in its temperature and density, the chromosphere stretches out into space to a distance far beyond our power of recognition.

MODES OF OBSERVING THE PROMINENCES IN SUNSHINE. FORM OF THE PROMINENCES.

As early as 1866, Lockyer attempted to observe the prominences in full sunshine by means of a Herschel-Browning spectroscope placed in combination with a telescope. The method he employed, and which he laid before the Royal Society in a special communication, depends on the specific difference between the light of the prominences and that of the sun itself.

The light of an incandescent solid or liquid body which passes through the slit of a spectroscope will be spread out by the prism into a band of greater or less length, and form a *continuous* spectrum.

The light of a gaseous or vaporous body will by the same means, on the contrary, be decomposed into a few only, sometimes even into a very few, bright *lines*.

In the first case, the greater the *length* of the spectrum, the less will be its intensity in comparison with that of the source of light; in the second case, especially when the spectrum consists only of a couple of lines, the intensity of each line is little less than half that of the light itself.

If, therefore, an equal amount of light from two self

luminous bodies, one of which is solid or liquid, and the other gaseous or vaporous, enter the slit of the spectroscope at the same time, the bright lines of the latter will be more brilliant than the color of the corresponding portion of the continuous spectrum.

Now, by *increasing* the number of prisms, the continuous spectrum may become so elongated, and consequently diminished in light, that the once brilliant solar spectrum may be reduced to the verge of visibility, while the same amount of dispersion produces on a spectrum of lines from glowing gas only an increase in the *distance between the lines*, and no considerable diminution of their brilliancy.

The reason why the prominences round the sun's limb cannot be seen through a telescope at any time by screening off the intense light of the sun, is owing to the extreme brilliancy with which the sun illuminates the earth's atmosphere, the particles of which scatter so large an amount of light as quite to overpower the fainter light of the prominences, and prevent them making any sensible impression on the eye.

In a total eclipse of the sun, the light of this atmosphere is so considerably reduced as to allow the larger prominences beyond the limb of the sun to be observed by the unassisted eye. The possibility of reducing the glare of sunlight at any other time without extinguishing the light of the prominences, rests on the circumstance already mentioned, that the light of the sun consists of rays of every color, and therefore produces in a spectroscope of highly dispersive power a long and faint spectrum, while the light of the *prominences*, consisting in general of only three or four kinds of rays, remains even after the greatest dispersive power still concentrated into the same number of lines ($H\alpha$, $H\beta$, $H\gamma$, D_3).

It was on these principles, first announced by Lockyer, that Janssen succeeded, the day after the eclipse of the 18th of August, 1868, in observing the *spectrum* of the prom-

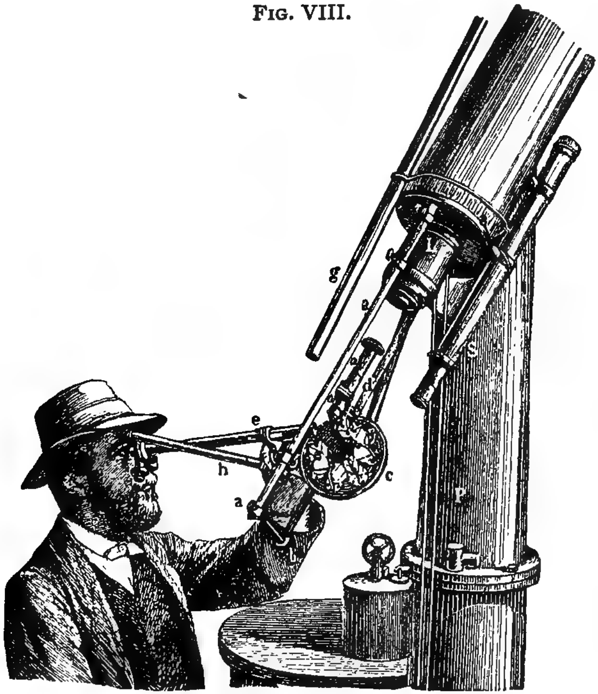
inences in sunshine. That the method he employed was no other than that suggested by Lockyer, is evident from his own communication to the French Academy, dated Calcutta, the 3d of October, 1868, in which he expressed himself as follows: "The principle of the new method rests upon the difference between the spectrum peculiarities of the light of the prominences and that of the photosphere. The light of the photosphere, which is derived from incandescent solid or liquid particles, is incomparably stronger than that of the prominences, which is derived from gases. On this account it has been impossible hitherto to see the prominences, except during a total solar eclipse. By the employment, however, of spectrum analysis, the circumstances of the case may be reversed. *In fact, by the process of analyzation, the light of the sun is dispersed over the whole range of the spectrum, and its intensity becomes considerably lessened. The prominences, on the contrary, furnish only a few detached groups of rays which are bright enough to bear comparison with the corresponding rays of the solar spectrum.* It is for this reason that the *lines* of the prominences may be seen easily in the same field of the spectroscope with the solar spectrum, while the direct images of the prominences are invisible on account of the overpowering light of the sun. Another circumstance very favorable to the new method of observation lies in the fact that the bright lines of the prominences correspond with the dark lines of the solar spectrum: they can, therefore, not only be more easily recognized in the field of the spectroscope along the edges of the solar spectrum, but also detected on the solar spectrum itself, and their traces even followed on the very surface of the sun."

As soon as Janssen and Lockyer had succeeded by this method in observing the *spectrum* of the prominences independently of a total eclipse, it became a question whether it would not be possible not merely to see the lines of the

prominences, but also to make their actual forms visible during sunshine.

It was on the principles before mentioned that Lockyer based his plan of observing the spectra of the prominences in full sunlight by means of a telespectroscope (Fig. VIII.).

FIG. VIII.



LOCKYER'S TELESPECTROSCOPE.

For this purpose the slit of a highly dispersive spectroscope, *d c e h*, firmly attached by the rods *a a b* to an equatorially mounted telescope L T P, driven by clockwork, is directed perpendicularly on to the edge of the sun's image formed in the telescope. By moving the tube *e* of the spectroscope

from end to end of the spectrum, and setting the focus each time, the bright lines of the prominences may be seen as *prolongations* of the dark lines of the spectrum of the sun's disk on a background of the exceedingly faint spectrum of the earth's atmosphere. In the picture, S is the finder, *g* a handle for moving the telescope in declination, *d* the tube containing the slit, *h* a small telescope for reading the divisions on the micrometer screw head, partly concealed by the rod *a a*.

The telespectroscope is furnished with seven prisms, and it confirmed, after a few trials, the correctness of this view, and he was the first to succeed, without additional mechanical help or the use of colored glasses, in observing the prominences at any time when the sun was visible, and tracing their complete outline.

By the same means Zöllner saw the prominences for the first time on the 1st of July, 1869. He has published the results of his observations, and accompanied them by a series of highly interesting drawings of some of the larger prominences, in which their origin, development, and subsequent disappearance are very clearly exhibited.

When the spectrum of the earth's atmosphere has disappeared in consequence of the *powerful dispersion of the light*, and the portion of the prominence then in the field of view alone is visible through the widely opened slit, the telescope or slit is moved slowly forward, and luminous images of the most wonderful forms flit before the eye, being just as easily observed as during a total solar eclipse. In describing some of these shadow forms, Lockyer writes, "Here one is reminded, by the fleecy, infinitely delicate cloud-films, of an English hedgerow with luxuriant elms; here of a densely intertwined tropical forest, the intimately interwoven branches threading in all directions, the prominences generally expanding as they mount upward, and changing slowly, indeed almost imperceptibly. . . . As a rule, the attachment to the chromosphere is narrow, and is not often

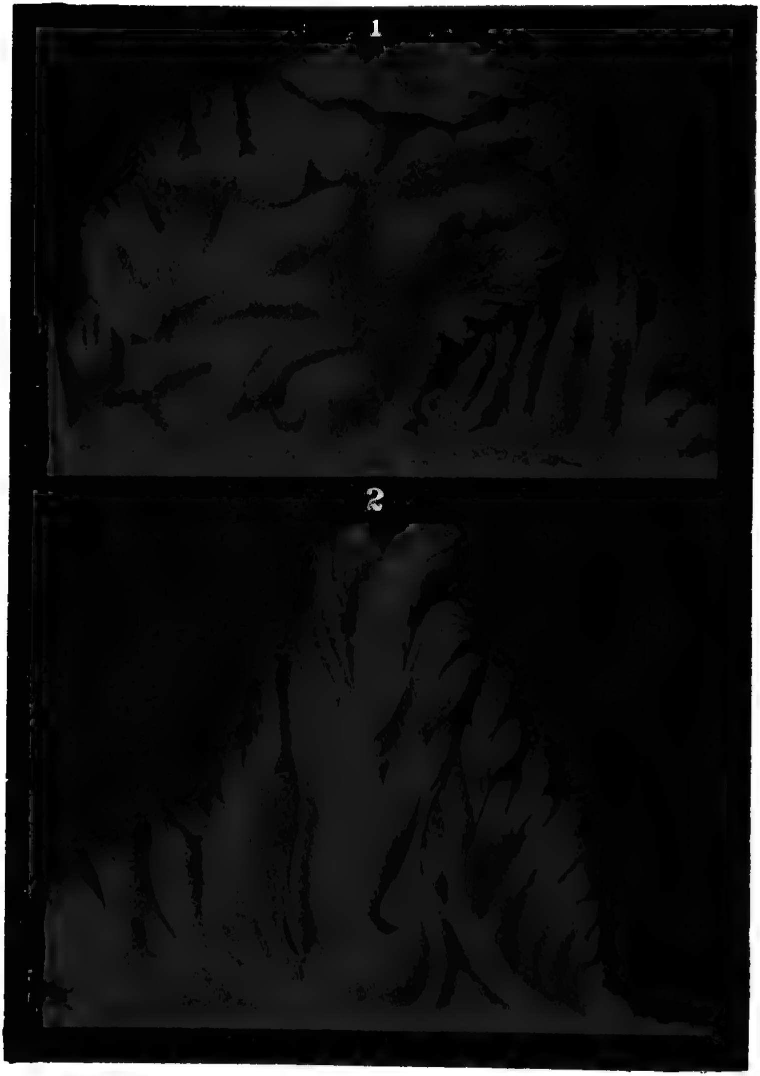
single; higher up, the stems, so to speak, intertwine, and the prominence expands and soars upward until it is lost in delicate filaments, which are carried away in floating masses."

The various forms of the prominences may be classified generally into two characteristic groups, very aptly designated by Zöllner as *vaporous* or *cloud-like* forms, and *eruptive* forms.

Slight changes in the form of the prominences may be watched almost without intermission with an open slit; great changes, as a rule, take place only very slowly, or quite imperceptibly. In some cases, however, the change in the form of a prominence is so extraordinary, and occurs with such rapidity, that it can only be ascribed to extremely violent agitation in the upper portions of the solar atmosphere, compared with which the cyclonic storms occasionally agitating the earth's atmosphere sink into insignificance. The observation of such a solar storm has been thus described by Lockyer: —

"On the 14th of March, 1869, about 9 h. 45 m., with a slit tangential to the sun's limb instead of radial, which was its usual position, I observed a fine dense prominence near the sun's equator, on the eastern limb, in which intense action was evidently taking place. At 10 h. 50 m., when the action was slackening, I opened the slit; I saw at once that the dense appearance had all disappeared, and cloud-like filaments had taken its place. At 11 h. 5 m., it was about twenty-seven thousand miles high, and the portion on the left resembled a straight column in a slightly leaning position. I left the Observatory for a few minutes, and on returning, at 11 h. 15 m., I was astonished to find that part of the straight prominence had entirely disappeared; not even the slightest rack appeared in its place: whether it was entirely dissipated, or whether parts of it had been wafted towards the other part, I do not know, although I think the latter explanation the more probable one, as the other part

Solar Prominence observed by Young
1869 Oct 7 & 8 Pos 70° 80°



No 1
Time Oct 7 2h 45m

English miles

No 2
Time Oct 8 1h 50m 4s

Tomson & Ramsay lith Boston

had increased. Fig. IX. shows the prominence as it appeared at the last observation.

FIG. IX.

STORM OBSERVED BY LOCKYER ON THE 14th MARCH, 1869.

Professor C. A. Young, of Dartmouth College, Hanover, N. H., has devoted himself especially to the observation of the forms and variability of the prominences. In the colored plate accompanying this paper are represented some of the forms and the color of the prominences. The one here shown is of the vaporous or cloud-like form, and was observed by Professor Young, October 7, 1869.

The change in the form between the first and second observation will serve to illustrate the motions of the hydrogen flames, and will give the reader some slight idea of the disturbances which are constantly occurring on the surface of the sun. By means of the accompanying scale their height

can be easily ascertained. Professor Young has since observed others of a much greater height and magnitude.

As the meteorologist registers many times in a day the conditions of our atmosphere, in the hope that a comparison of the observations may lead to a discovery of the law governing these changes, so has Respighi, Director of the University Observatory at the Campidoglio at Rome, made it his daily task since October, 1869, to observe the entire limb of the sun, when the weather was favorable, including the chromosphere and prominences, and to mark upon a straight line representing the circumference of the sun the position, height, and form of the prominences for each day. By collating these lines or circumferences of the sun one below the other, and crossing them with lines indicating the principal positions, a comprehensive picture is afforded of the distribution of the prominences round the sun's limb, which shows at a glance those regions in which the prominences abound, and those in which they are least frequently to be met with.

By a comparison of the maps already constructed, Respighi has arrived at the following results:—

1. In the polar regions prominences occur only exceptionally. The district from which they are absent lies between north and north-east on the one side, and south and south-west on the other; the portion which is almost entirely without prominences has a semi-diameter of $22\frac{1}{2}°$.

2. The district where the prominences most frequently occur lies between north and north-west, at about 45° north latitude, in a region where solar spots are rarely seen.

3. The prominences are, therefore, phenomena quite distinct from the spots; they are probably more intimately connected with the formation of *faculæ*.

4. The various forms of the prominences show that they are not of the nature of *clouds*, which float in an atmosphere in which they are produced by local condensations; they are much more like *eruptions* out of the chromosphere,

which often spread out of the higher regions, and take the form of bouquets of flowers, some being bent over on one side, and some on the other, and which fall again on to the surface of the chromosphere as rapidly as they rose from it.

5. It appears that *eruptions of hydrogen* take place from the interior of the sun; their form and the extreme rapidity of their motion necessitates the hypothesis of a *repulsive power*, at work either at the surface or in the mass of the sun, which Respighi attributes to electricity, but Faye simply to the action of the intense heat of the photosphere.

On the 28th of September, 1870, Professor Young succeeded for the first time in photographing the prominences on the sun's limb in bright sunshine. This he effected by bringing the blue hydrogen line H γ near G into the middle of the field of the spectroscope, and placing a small photographic camera in connection with the eye-piece of the telescope. As the chemicals employed were those ordinarily used in taking portraits, the requisite time of exposure was three and one half minutes, during which time the image of the prominence suffered a slight displacement on the prepared plate, owing to a want of accuracy in the perfect adjustment of the polar axis. Still, however, the various forms of the prominences could be clearly discerned in the photograph, which was half an inch in diameter, so that the possibility of photographing the prominences has been proved by Young's experiment.

MEASUREMENT OF THE DIRECTION AND SPEED OF THE GAS-STREAMS IN THE SUN.

One of the most glorious triumphs of spectrum analysis — surpassing, perhaps, in splendor all its other wonderful achievements — is the discovery that, by means of accurate measurements, undertaken with the best instruments, of the position, or rather of the small *displacement in the position* of the spectrum lines of a star or other source of light, — a

prominence, for instance, — it is possible to ascertain whether this luminous body be approaching us or receding from us, and at what speed it is travelling.

The pitch of a musical tone depends, as is well known, upon the number of impulses which the ear receives from the air in a given time (p. 74). Now, as a tone rises in pitch the greater the number of air vibrations which strike the tympanum in a second, so must a sound ascend in tone if we rapidly approach it, and fall in pitch if we recede from it. The truth of this supposition may be fully proved by the whistle of a railway engine in rapid motion. To an observer standing still, the pitch of the tone rises on the rapid approach of the locomotive, although the same note is sounded, and falls again as the engine travels away.

As the various tones of sound depend on the rapidity of the air vibrations, so the varieties of color are regulated by the number of ether vibrations (p. 77). If, therefore, a luminous object — as, for instance, the glowing hydrogen of a prominence — be *receding* rapidly from us, fewer waves of ether will strike the optic nerve in a second than if it were stationary. If the difference in the number of ether waves be sufficiently great to be perceived by the eye, then each color of the glowing gas must sink in the scale of the spectrum, — that is to say, incline more towards the red. The individual colored rays will not then, in the prismatic decomposition of the light, occur in the same place of the spectrum in which they would have appeared had the light been stationary; they will all be displaced somewhat towards the *red*.

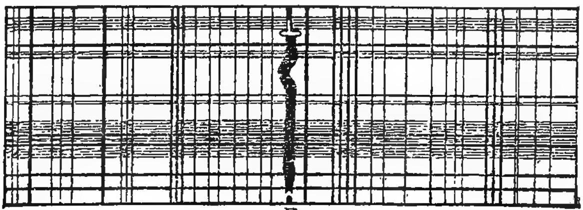
The converse takes place when the luminous body is rapidly approaching us: the number of ether vibrations received by the eye is then increased beyond what it would be if the source of light were stationary; in the prismatic analysis of the light, the colored rays will be found likewise to have changed their place in the scale of the spectrum, and taken a position in accordance with their increased re-

frangibility, suffering a general displacement towards the *violet.*

When it is remembered that the number of ether waves in red light is at least 480 billion, and in violet 800 billion in a second, and that moreover the wave length of the greenish-blue light (H β), situated at the spot marked F in the solar spectrum, is only 485 millionth of a millimetre, and that instruments of sufficient delicacy to measure these minute quantities are required for this purpose, there will be little danger of under-estimating the extreme difficulty connected with observations of this displacement in the colors of the spectrum. Indeed, these observations would scarcely be possible, were it not that in the dark lines crossing the spectra of the sun and fixed stars, the places of some of which may be accurately ascertained, we have fixed positions in the spectrum, the degree of refrangibility or wave-length of which may be determined beforehand, both for the sun and terrestrial substances, and also for the stars or other sources of light supposed to be at rest.

Fig. X., which is from a drawing by Lockyer, shows clearly what remarkable changes take place in the dark line

FIG. X.



F

Displacement of the F-line; Velocity of the Gas-streams in the Sun.

F when the spectroscope is directed to a solar spot in the middle of the sun. The F-line, which, as a rule, is sharply defined at the edges, appears in some places not merely as a

bright line, but as a bright and dark line twisted together, in which parts it suffers the greatest displacement towards the red. When this occurs, there is frequently also a bright line to be seen on the violet side. In small solar spots, this line sometimes breaks off suddenly, or spreads out immediately before its termination in a globular form; over the bright faculæ of a spot (the bridges) the line is often altogether wanting, or else it is reversed, and appears as a bright line.

The same phenomena are exhibited also by the red C-line (H α), though as the greenish-blue F-line (H β) is by an equal increase of pressure much more sensitive with regard to expansion than the red line is, and exhibits with greater distinctness the changes that have been already described, it is better adapted to observations of this kind.

All these expansions, twistings, and displacements of the F-line result from a change in the wave-length of the greenish-blue light emitted by the moving masses of incandescent hydrogen gas in the sun. The middle of this line, when it is well defined, corresponds to a wave-length of 485 millionth of a millimetre, yet it is possible, by means of Angström's maps of the solar spectrum, to measure a displacement of this line when the wave-length has only changed as much as $\frac{1}{10,000,000}$ of a millimetre, and, inversely, it is also possible to read off at once, by the measured displacement of the F-line, the corresponding amount which the wave-length of the greenish-blue hydrogen light has lengthened or shortened, to ten millionth of a millimetre. In observing a prominence, if the F-line were to be displaced from its normal place in the solar spectrum $\frac{1}{10,000,000}$ of a millimetre, the light would be approaching the eye of the observer, and an eruption of gas be *ascending* at the spot observed in the middle of the sun, and would be approaching the earth at the rate of thirty-six miles per second.

If the F-line were to suffer an equal displacement to the left, that is to say, towards the red, the wave-length of the greenish-blue hydrogen light would then be lengthened; the

gas would therefore be moving away from the earth at the same rate of thirty-six miles in a second, and the stream of gas be sinking down to the surface of the sun.

Fig. XI. shows the displacement which occurs when a cyclone takes place on the sun's surface. Such a circular storm or cyclone was observed by Lockyer on the sun's limb, on the 14th of March, 1869. With the first setting of

FIG. XI.

MOVEMENT OF A GAS-VORTEX IN THE SUN.

the slit, the image of the bright F-line (H β) in the chromosphere appeared in the spectroscope, as in No. 1; a slight alteration of the slit gave in succession the pictures 2 and 3. There occurred also a simultaneous displacement of the bright F-line towards both the red and violet—a sign that at that place on the sun a portion of the hydrogen was moving towards the earth, while another portion was going in an opposite direction away from the earth towards the sun, and thus the whole action of the gas in motion resembled that of a whirlwind.

By means of the distances from the normal dark F-line which are taken from Angström's maps, Lockyer found that the furthest displacement of the bright F-line corresponded to a shortening of the wave-length that indicated a velocity in the stream of gas of at least one hundred and forty-seven

miles in a second in the direction from the sun towards the earth.

These spectroscopic observations receive an additional interest when taken in connection with those made with the telescope. On the 21st of April, 1869, Lockyer observed a spot in the neighborhood of the sun's limb. At 7 h. 30 m., a prominence showing great activity appeared in the field of view. The lines of hydrogen were remarkably brilliant, and as the spectrum of the spot was visible in the same field, it could be seen that the prominence was advancing towards the spot. The violence of the eruption was so great as to carry up a quantity of metallic vapors out of the photosphere in a manner not previously observed. High up in the flame of hydrogen floated a cloud of magnesium vapor. At 8 h. 30 m. the eruption was over; but an hour later another eruption began, and the new prominence displayed a motion of extreme rapidity. Whilst this was taking place, the hydrogen lines at the side of the spot nearest to the earth were suddenly changed into bright lines, and expanded so remarkably as to give undoubted evidence of the occurrence of a cyclonic storm.

The sun was photographed at Kew on the same day at 10 h. 55 m.; the picture showed clearly that great disturbances had taken place in the photosphere in the neighborhood of the spot observed by Lockyer. In a second photograph, taken at 4 h. 1 m., the sun's limb appeared as if torn away just at the place where the spectroscope had revealed a rotatory storm.

Who could have dreamed, ten years ago, that we should so soon attain such an insight into the processes of creation? And yet, great though the results of spectrum analysis already are, they are but a tithe of the numerous questions which this branch of discovery has opened up, — questions of such number and magnitude, that many generations of men will pass away before they are all satisfactorily answered.

SPECTRA OF THE MOON AND PLANETS.

Since the planets and their satellites do not emit light of their own, but shine only by the reflected light of the sun, their spectra are the same as the solar spectrum, and any differences that may be perceived can arise only from the changes the sunlight may undergo by reflection from the surfaces of these bodies, or by its passage through their atmospheres.

The observations of Huggins and Miller, as well as Janssen, agree in establishing the complete accordance of the lunar spectrum with that of the sun. In all the various portions of the moon's disk brought under observation, no difference could be perceived in the dark lines of the spectrum, either in respect of their number or relative intensity. From this entire absence of any special absorption lines, it must be concluded that there is no atmosphere in the moon, — a conclusion previously arrived at from the circumstance that during an occultation no refraction is perceived on the moon's limb when a star disappears behind the disk.

The spectra of the planets Venus, Mars, Jupiter, and Saturn are also characterized by the Fraunhofer lines peculiar to the solar light, but contain, in addition, the absorption lines which are known to be telluric lines, and are evidence of the presence of an atmosphere containing aqueous vapor.

The spectrum of Jupiter, which has been recently examined by Browning with a spectroscope attached to his 12½-inch reflector, is not of sufficient brilliancy to allow of its being observed or measured with extreme accuracy. Notwithstanding the great brilliancy with which this planet shines in the heavens, its spectrum is not so bright as that of a star of the second magnitude; this is owing to the brightness being more apparent than real, and arises from the large size of the disk compared with a star, and from the light being reflected, and not original.

The comparatively faint spectrum of Saturn has been examined by Huggins, who observed in it some of the lines characteristic of Jupiter's spectrum. These lines are less clearly seen in the light of the ring than in that of the ball, whence it may be concluded that the light from the ring suffers less absorption than does the light from the planet itself. The observations of Janssen, which have been supported by Secchi, have since shown that aqueous vapor is probably present both in Jupiter and Saturn. Secchi has further discovered some lines in the spectrum of Saturn which are not coincident with any of the telluric lines, nor with any of the lines of the solar spectrum produced by the aqueous vapor of the earth's atmosphere. It is not improbable, therefore, that the atmosphere of Saturn may contain gases or vapors which do not exist in that of our earth.

The spectrum of Uranus, which has been investigated by Secchi, appears to be of a very remarkable character. It consists mainly of two broad black bands, one in the greenish-blue, but not coincident with the F-line, and the other in the green, near the line E. A little beyond the band the spectrum disappears altogether, and shows a blank space extending entirely over the yellow to the red, where there is again a faint re-appearance of light. The spectrum is therefore such a one as would be produced were all the yellow rays extinguished from the light of the sun. The dark sodium line D occurs, as is well known, in the part of the spectrum occupied by this broad, non-luminous space: is this extraordinary phenomenon, therefore, to be ascribed to the influence of this metal, or is the planet Uranus, which has a spectrum differing so greatly from that of the sun, self-luminous? Has the planet not yet attained that degree of consistency possessed by the nearer planets, which shine only by the sun's light, and, as the photometric observations of Zöllner lead us to suppose is possible, is still in that process of condensation and subsequent development through which the earth has already passed? These are

questions to which, at present, we can furnish no reply, and the problem can only be solved by additional observations of the strange characteristics exhibited by this spectrum.

While Jupiter and his satellites, with a power of 350, give a sharply defined image, the disk of Neptune, with the same power, ceases to be well defined, and appears with a nebulous edge. From this it may be inferred that the planet is surrounded by a dense mist of considerable extent, the chemical nature of which has yet to be discovered, or else that, like Jupiter, Saturn, and Uranus, it has not yet attained that degree of density which must necessarily precede the formation of a solid surface.

SPECTRA OF THE FIXED STARS.

The fixed stars, though immensely more remote, and less conspicuous in brightness than the moon and planets, yet from the fact of their being *original sources of light*, furnish us with fuller indications of their nature. In all ages, and among every people, the stars have been the object of admiring wonder, and not unfrequently of superstitious adoration. The greatest investigators and the deepest thinkers who have devoted themselves to the study of the stars, have felt a longing to know more of these sparkling mysteries.

The telescope has been appealed to, but in vain, for in the largest instruments the stars remained diskless, never appearing more than as brilliant points. The stars have indeed been represented as *suns*, each surrounded by a dependent group of planets, but this opinion rested only upon a possible analogy, for of the *peculiar nature* of these points of light, and of what substances they are composed, the telescope yields us no information. Spectrum analysis alone can disclose to us this much-coveted knowledge, as it gives us the means of reading, in the light emitted by these heavenly bodies, the indications of their true nature and physical constitution. In this light we possess a telegraphic communi-

cation between the stars and our earth; the spectroscope is the telegraph, the spectrum lines are individually the letters of the alphabet, their united assemblage as a spectrum forms the telegram. It is not, however, easy to comprehend this language of the stars, but through the indefatigable labors of Secchi, Huggins, and Miller, most of the bright stars, the nebulæ, and some of the comets have been investigated by spectrum analysis, and valuable evidence obtained as to their physical constitution.

As the spectra of the stars bear in general a marked resemblance to the spectrum of the sun, being continuous, and crossed by dark lines, there is every reason for applying Kirchhoff's theory also to the fixed stars, and for accepting the same explanation of these similar phenomena that we have already accepted for the sun. By the supposition that the vaporous *incandescent* photosphere of a star contains or is surrounded by heated vapors, which absorb the same rays of light which they would emit when self-luminous, we may discover from the dark lines in the stellar spectra the substances which are contained in the photosphere or atmosphere of each star. In order to ascertain this with certainty, the dark lines must be compared with the bright lines of terrestrial substances volatilized in the electric spark; and the complete coincidence of the characteristic bright lines of a terrestrial substance with the same number of dark lines in the stellar spectrum, would justify the conclusion that this substance is present in the atmosphere of the star — a conclusion that gains all the more in certainty, the greater the number of lines coincident in the two spectra.

The fact that certain stars possess an atmosphere of aqueous vapor has been observed both by Janssen and Secchi. They belong, for the most part, to the class of red and yellow stars, and in their spectra, as might be supposed, the lines of luminous hydrogen are wanting. As early as 1864, Janssen had remarked the existence of an atmosphere of aqueous vapor in the star Antares; and after a more com-

plete investigation of the spectrum of steam in 1866, and further observations of stellar spectra, made after the total solar eclipse of 1868 in the remarkably dry air of the heights of Sikkim (Himalaya), he could no longer doubt that there are many stars surrounded by a similar atmosphere. Notwithstanding the dry condition of the air, the lines of aqueous vapor were more strongly marked in the spectra of these stars, as seen from the heights of the Himalaya, than had been observed previously — a phenomenon which cannot be ascribed to the absorption of the earth's atmosphere, and must therefore be due to that of the star.

From all the observations thus far made, it may be concluded that at least the brightest stars have a physical constitution similar to that of our sun. Their light radiates, like that of the sun, from matter in a state of intense incandescence, and passes, in like manner, through an atmosphere of absorptive vapors. Notwithstanding this general conformity of structure, there is yet a great difference in the constitution of individual stars; the grouping of the various elements is peculiar and characteristic for each star, and we must suppose that even these individual peculiarities are in necessary accordance with the special object of the star's existence, and its adaptation to the animal life of the planetary worlds by which it is surrounded.

COLOR OF THE STARS. — DOUBLE STARS AND THEIR SPECTRA.

In a transparent atmosphere, especially in a southern clime, the stars do not all appear with the white brilliancy of the diamond: here and there the eye discovers richly-colored gems, sparkling on the sombre robe of night, in every shade of red, green, blue, and violet; and the astronomer, enabled by his powerful telescope to investigate the faintest objects, is lost in wonder over the variety of these colors, and their remarkable distribution in the starry

heavens. This play of color is most conspicuous in the *double stars*, so called from their consisting of two or more suns, kept together by the bond of mutual attraction, and revolving in orbits according to their mass, either one around the other or both round a common centre of gravity. To the naked eye their appearance is that of a single star, on account of their close proximity; but on the application of sufficient magnifying power, they are found to be constituted of three, four, or more suns in intimate connection: such a system is to be found in the beautiful constellation of Orion (in the Sword), consisting of six stars, where to the unassisted eye there seems but one. In several of these double stars, the number of which already exceeds six thousand, it has been possible to calculate the time of revolution of the small star. The period of one in the Great Bear has been found to be sixty years; of another, in Virgo, five hundred and thirteen years; and of γ Leonis twelve hundred years.

A peculiar interest attaches to double stars from their great diversity of color, which occasioned Sir John Herschel to remark, in describing a cluster in the Southern Cross, that it resembled a splendid ornament composed of the richest jewels. While the majority of single stars shine with a white light, but sometimes with a yellow, and even occasionally with a red hue, in double stars the companion is almost always blue, green, or red; thus contrasting with the white light of the larger or central star.

It has long been a subject of inquiry whence these colors arise. It has been supposed that they were complementary colors, and therefore that they were not inherent in the stars, but dependent on an optical illusion similar to that produced by looking upon a white wall immediately after gazing at the sun, when the wall appears covered with violet spots. But the simple expedient of covering the central star in the telescope suffices to show the incorrectness of this supposition; for the color of the small star remains unaffected by its separation from the light of the larger one. Zöllner, to

whom we are indebted for a masterly work on light and the physical constitution of the heavenly bodies, was the first to express the idea that, as all known substances, in their transition from a state of incandescence to that of a lower temperature, pass through the stage of red heat, so the fixed stars, in their process of development from the condition of glowing gas through the period of an incandescent liquid state, and the subsequent development of floating scoriæ, or gradual formation of a cold, non-luminous surface, must, together with the gradual diminution of their light, be also subject to a change of color. For many colored stars, especially for the so-called *new* stars, in which the color has been known to sink in the scale from white to yellow and to red, this conjecture of Zöllner's has a high degree of probability; but that other circumstances must exercise an influence also on the color of stars, is proved by a change of color having been observed to take place in the opposite direction, — that is, from red to white, — of which, among other stars, we have an example in Sirius, regarded by the ancients as a red star, and which is now considered as a type of the white stars, as well as in Capella, which formerly was red, and now shines with a pale blue light. Huggins and Miller have discovered, by means of the spectroscope, that the color of a star not only depends upon the degree of incandescence of the intensely hot liquid or solid nucleus, but also upon the kind of absorptive power its atmosphere may exert upon the light emitted by the glowing nucleus.

As the source of stellar light, remarks Huggins, is incandescent solid or liquid matter, it appears very probable that at the time of its emission the light of all stars is alike *white*. The colors in which we see them must therefore be produced by certain changes which the light has undergone since its emission. It is further obvious that if the dark absorption lines are more numerous, or more strongly marked in some parts of the spectrum than in others, then the peculiar colors of those places will be subdued in tone, and in

any case will appear relatively weaker than in those parts of the spectrum where the absorption lines are much less numerous. While in this way certain colors would be partially extinguished from the spectrum, the remaining colors, being unaffected, would predominate, and give their own tints to the originally white light of the star.

The colors of the stars are, therefore, without doubt produced by the vapors of certain substances contained in their atmosphere; and as the chemical constitution of the atmosphere of a star depends upon the elements of which the star itself is composed, and upon its temperature, it would be possible to ascertain the chief constituents of these small telescopic worlds, if the position of the dark absorption lines could be determined with accuracy, or if these lines could be compared with the spectrum lines of terrestrial elements.

VARIABLE STARS.

Among the fixed stars there are several which vary, from time to time, in brightness, as compared with neighboring stars; their light increases or diminishes, and alternates, in some cases, from the brilliancy even of a star of the first magnitude to complete invisibility. In some, this change of brightness takes place as a constant, very slow and regular diminution of light; in others, there appears an almost sudden increase and decrease of brilliancy; while with others, again, the change takes place within regularly recurring periods. The *period* of variability is, therefore, the time elapsing between the two successive seasons of greatest brilliancy.

Of all variable stars, Mira Ceti is perhaps the most interesting, since, at its maximum brightness, it equals a star of the first or second magnitude. Scarcely less interesting is β Persei, which, for two days thirteen hours and a half, shines with the brightness of a star of the second magnitude, then suddenly decreases in light, and sinks down, in three

hours and a half, to a star of the fourth magnitude; its light then again increases, and in a similar period of three hours and a half regains its original brilliancy. All these changes recur regularly in the space of less than three days, during which the star always remains visible to the naked eye.

Whence comes this variation in the light of a star? Zöllner, with great acuteness, and supported by numerous observations of these changes of brightness, offers a simple and unconstrained explanation, in supposing the cause to lie in the configuration and distribution of dark masses of scoriæ, which form on the red-hot liquid body of the star in the process of cooling, and which, in consequence of the star's rotation on its axis, and the centrifugal force thus arising, would take certain definite courses on the surface of the star in a manner analogous to that which may be observed with floating icebergs on our earth. As a consequence of this peculiar relative motion, the dark masses of scoriæ would arrange themselves in a fixed order, and would produce on the surface of the star an unequal distribution of red-hot luminous matter, and accumulations of non-luminous scoriæ.

It has recently been remarked by Secchi that the spectrum of the nucleus of a solar spot bears a close resemblance to that given by several red stars, such as α Orionis, Antares, Aldebaran, o Ceti. A series of dark bands and stripes, as represented in the spectrum of α Orionis, are present equally in the spectrum of a solar spot as in the spectra of the above named red stars, which leads to the supposition that the red color of these stars arises from the same cause that produces the absorption bands in the spectrum of the solar spot. As nearly all these stars are variable, it is not improbable that they are also subject to spots which occur with a certain degree of regularity, as the solar spots have been proved to do. The period of variability in the light would then depend upon the period of the formation of the spots, in the same way as our sun appears as a variable star, of which the

period of variation in the light coincides with the regular recurrence of the spots.

NEW OR TEMPORARY STARS.

Among the variable stars must also be reckoned those which, from time to time, but only at exceedingly long intervals, have suddenly flamed forth in the sky and disappeared again after a longer or shorter interval, and which always excite the greatest wonder and interest, not only from the rarity of their appearance, but also from the mighty revolutions in space which they announce. According to Humboldt, only twenty-one such stars have been recorded in the space of two thousand years, — from 134 B. C. to 1848 A. D., — the most remarkable of which was that observed by Tycho Brahe (1572) in Cassiopeiæ, which surpassed both Sirius and Jupiter, and even rivalled Venus in brilliancy, but disappeared after seventeen months, without leaving a trace visible to the naked eye; * and that seen by Kepler (1604) in the right foot of Ophiuchus, which excelled Jupiter, but did not quite equal Venus, in brightness, and at the end of fifteen months was visible only by means of the telescope. Two similar stars, which have appeared in recent times, — one observed by Hind, in 1848, and another seen in the Northern Crown, in 1866, — though they soon lost their ephemeral glory, still continue visible as stars of the tenth and ninth magnitude. A characteristic peculiarity of these temporary stars is, that they nearly all flash out at once with a degree of brilliancy exceeding, in some cases, even stars of the first magnitude, and that they have not been observed, at least with the naked eye, to increase gradually in brightness.

Are we to suppose that these so-called *new* stars are really

* The telescope was not invented until thirty-seven years after this date.

new creations, as Tycho Brahe believed, and that those that have disappeared are really annihilated or burned out? Can we suppose, with Riccioli, that these heavenly bodies are luminous only on one side, which by a sudden semi-revolution the Creator, at the appointed time, has turned towards us? The first supposition has been set aside by later observations, which have shown, by the help of maps, that a small star had already existed precisely in the place where the new star burst forth; the other view is too absurd to deserve, in these days, any further consideration. The star observed by Tycho, as well as that one seen by Kepler, are still visible. If, therefore, the sudden bursting forth of a star in the heavens does not denote the creation of a new star, nor its gradual disappearance indicate its complete annihilation, we may well suppose that both phenomena are the successive effects of a violent outbreak of fire taking place in the star, either in the form of an eruption of the internal red-hot liquid matter, and its suffusion over the surface, or of the ignition of gigantic streams of gas forcing their way from the interior. While such an occurrence would raise the star to a state of extreme incandescence, and cause it to emit an intense light for some time, the cooling subsequent to this combustion would ensue more or less rapidly, and the brightness consequently diminish in quick progression, until, in certain conditions, the star would cease to be visible.

Fortunately for science, such an occurrence has taken place since spectrum analysis has been so successfully applied to the examination of the heavenly bodies. On the night of the 12th of May, 1866, a new star, brighter than one of the second magnitude, was observed at Tuam, by Mr. John Birmingham, in the constellation Corona Borealis. On the following night it was seen by the French engineer, Courbebaisse, at Rochefort, and was observed a few hours earlier at Athens by the astronomer Julius Schmidt, who expressly declares that the new star could not have been vis-

ible before eleven o'clock on the night of the 12th of May, as he had been observing with his comet-seeker the star R Coronæ, and while sweeping for some time in its neighborhood for comets, could not have failed to notice the new star, if it had been then visible. On the next night (13th of May) the light of the star sensibly decreased, and by the 16th of May it had become only of the fourth magnitude. Its brightness then waned somewhat rapidly: it decreased from 4.9 on the 17th to 5.3 on the 18th, and from 5.7 on the 19th to 6.2 on the 20th, till, by the end of the month, it had become a star of the ninth magnitude.

Argelander observed the star on the 18th of May, 1855, and on the 31st of March, 1856, and on both occasions had classed the star as between the ninth and tenth magnitudes.

Huggins was informed by Birmingham of his discovery on the 14th of May, and was thus enabled, on the 15th inst., in conjunction with Miller, to examine the spectrum of this star when it had not fallen much below the third magnitude. The result of this investigation is as follows.

The spectrum of the star was very remarkable, and showed clearly that there were two distinct sources of light, each producing a separate spectrum, one a discontinuous spectrum, crossed by dark lines similar to that given by the sun and other stars, while the other consists of *four bright* lines, which, from their great brilliancy, stand in bold relief upon the dark background of the first spectrum.

The principal spectrum traversed by dark lines shows the presence of a photosphere of incandescent matter, probably solid or liquid, which is surrounded by an atmosphere of cooler vapors, giving rise by absorption to the dark lines. This absorption spectrum contains two strong dark bands, of less refrangibility than the D-line of the solar spectrum; a group of fine lines stretches from them close up to D, while one fine line is quite coincident with D. Up to this point, the constitution of this object is analogous to that of the sun and the stars; but the star has also a spectrum con-

sisting of bright lines, which denotes the presence of a second source of light, which, from the nature of the spectrum, is undoubtedly an intensely luminous gas.

Huggins compared the spectrum of the star on the 17th of May with the spectrum of hydrogen gas produced by means of the induction spark through a Geissler's tube, and found that the strongest of the stellar lines 2 was coincident with the greenish-blue line H β of hydrogen gas. Apparently, also, the line 1 in the red coincided with the H α-line of hydrogen, but owing to the want of brilliancy of the line, the coincidence could not be ascertained with the same degree of certainty. The great brilliancy of these lines, compared with the parts of the continuous spectrum where they occur, proves that the luminous gas was at a higher temperature than the photosphere of the star.

These facts, taken in connection with the suddenness of the outburst of light in the star, and the immediate very rapid decline in its brightness from the second down to the eighth magnitude, have led to the hypothesis already alluded to, that, in consequence of some internal convulsion, enormous quantities of hydrogen and other gases were evolved, which, in combining with some other elements, ignited on the surface of the star, and thus enveloped the whole body suddenly in a sheet of flame. The ignited hydrogen gas, in its combination with some other element, produced the light characterized by the two bright bands in the red and green; the remaining bright lines, among which those of oxygen might have been expected, were not coincident with any of the lines of this gas. The burning hydrogen gas must also have greatly increased the heat of the solid matter of the photosphere, and brought it into a state of more intense incandescence and luminosity, which may explain how the formerly faint star could so suddenly assume such remarkable brilliancy. As the liberated hydrogen gas became exhausted, the flame gradually abated, and with the conse-

quent cooling the photosphere became less vivid, and the star returned to its original condition.

Robert Meyer and H. J. Klein have expressed the opinion that the sudden blazing out of a star might be occasioned by the violent precipitation of some great mass, perhaps of a planet, upon a fixed star, by which the momentum of the falling mass would be changed into molecular motion, or, in other words, into heat and light. It might even be supposed that the star in Corona, through its motion in space, may have come in contact with one of the nebulæ, which traverse in great numbers the realms of space in every direction, and which, from their gaseous condition, must possess a high temperature. Such a collision would necessarily set the star on a blaze, and occasion the most vehement ignition of its hydrogen.

It must not be forgotten that light, though an extremely quick messenger, yet occupies a certain time in coming to us from a star. The speed of light is one hundred and eighty-five thousand miles in a second. The distance of the nearest fixed star (α Centauri) is about sixteen billion miles, so that light takes about three years to travel from this star to us. The great physical convulsion which was observed in the star in Corona, in the year 1866, was therefore an event which had really taken place long before that period, at a time, no doubt, when spectrum analysis, to which we are indebted for the information we obtained on the subject, was yet quite unknown.

The discoveries made by means of spectrum analysis, connected with at least three classes of heavenly bodies, still remain to be reviewed, and will form the basis of another paper of this series, which will be entitled Nebulæ, Comets, and Meteors.

6. Nebulæ, Comets, Meteoric Showers,

And the Revelations of the Spectroscope regarding them.

SPECTRA OF NEBULÆ.

WE now come to treat of the remotest realms of the Universe, those regions of stellar clusters and nebulæ which can only be reached by means of the most powerful telescopes. When the starry heavens are viewed through a telescope of moderate power, a great number of stellar clusters and faint nebulous forms are revealed against the dark background of the sky, which might be taken at first sight for passing clouds, but which, by their unchanging forms and persistent appearance, are proved to belong to the heavenly bodies, though possessing a character widely differing from the point-like images of ordinary stars. Sir William Herschel was able, with his gigantic forty-foot telescope, to resolve many of these nebulæ into clusters of stars, and found them to consist of vast groups of individual suns, in which thousands of fixed stars may be clearly separated and counted, but which are so far removed from us that we are unable to perceive their distance one from the other, though that may really amount to many millions of miles, and their light, with a low magnifying power, seems to come from a large, faintly-luminous mass. But all nebulæ were not resolvable with this telescope, and in proportion as such nebulæ were resolved into clusters of stars, new nebulæ appeared which resisted a power of six thousand, and suggested to this astute investigator the theory that, besides the many thousand apparent nebulæ which reveal themselves to us as a complete and separate system of worlds, there are also thousands of real nebulæ in the Universe, composed of *primeval cosmical matter, out of which future worlds were to be fashioned.*

Lord Rosse, by means of a telescope of fifty-two feet focus, of his own construction, was able to resolve into clusters of stars many of the nebulæ not resolved by Herschel; but there were still revealed to the eye, thus carried farther into space, new nebulæ beyond the power even of this gigantic telescope to resolve.

Telescopes failed, therefore, to solve the question whether the unresolved nebulæ are portions of the primeval matter out of which the existing stars have been formed; they leave us in uncertainty as to whether these nebulæ are masses of luminous gas, which, in the lapse of ages, would pass through the various stages of incandescent liquid (the sun and fixed stars), of scoriæ or gradual formation of a cold and non-luminous surface (the earth and planets), and finally of complete gelation and torpidity (the moon), or whether they exist as a complete and separate system of worlds; telescopes have only widened the problem, and have neither simplified nor solved its difficulties.

That which was beyond the power of the most gigantic telescopes has been accomplished by that apparently insignificant, but really delicate, and almost infinitely sensitive instrument, the spectroscope. We are indebted to it for being able to say with certainty that luminous nebulæ *actually exist as isolated bodies in space*, and that these bodies are *luminous masses of gas*.

The spectroscope, in combination with the telescope, affords means for ascertaining, even now, some of the phases through which the sun and planets have passed in their process of development or transition from masses of luminous nebulæ to their present condition.

Great variety is observed in the forms of the nebulæ: while some are chaotic and irregular, and sometimes highly fantastic, others exhibit the pure and beautiful forms of a curve, a crescent, a globe, or a circle.

The largest and most irregular of all the nebulæ is that in the constellation of Orion (Fig. XII.). It is situated rather

below the three stars of second magnitude composing the central part of that magnificent constellation, and is visible to the naked eye. It is extremely difficult to execute even a tolerably correct drawing of this nebula; but it appears, from the various drawings, made at different times, that a

FIG. XII.

South.

North.

Central and most brilliant portion of the great Nebula in the Sword-handle of Orion, as observed by Sir John Herschel in his 20-foot Reflector at Feldhausen, Cape of Good Hope (1834 to 1837).

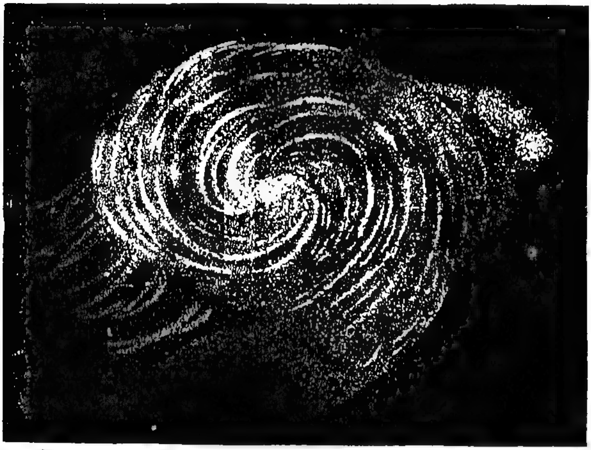
change is taking place in the form and position of the brightest portions. Fig. XII. represents the central and brightest part of the nebula. Four bright stars, forming a trapezium, are situated in it, one of which only is visible to the naked eye. The nebula surrounding these stars has a flaky appear-

ance, and is of a greenish-white color; single portions form long curved streaks, stretching out in a radiating manner from the middle and bright parts.

The interest aroused by these irregular and chaotic nebulous forms is still further increased by the phenomena of the spiral or convoluted nebulæ with which the giant telescopes of Lord Rosse and Mr. Bond have made us further acquainted. As a rule, there streams out from one or more centres of luminous matter innumerable curved nebulous streaks, which recede from the centre in a spiral form, and finally lose themselves in space.

Fig. XIII. represents the most remarkable of all the spiral nebulæ, which is situated in the constellation Canes Venatici.

FIG. XIII.

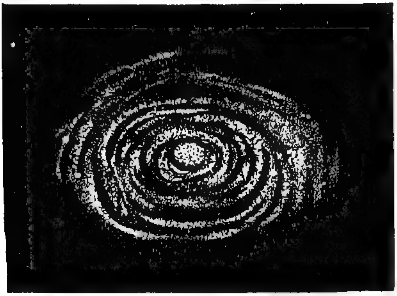


SPIRAL NEBULA IN CANES VENATICI.

It is hardly conceivable that a system of such a nebulous form could exist without internal motion. The bright nucleus, as well as the streaks curving round it in the same direction, seem to indicate an accumulation of matter towards

the centre, with a gradual increase of density, and a rotatory movement. But if we combine with this motion the supposition of an opposing medium, it is difficult to harmonize

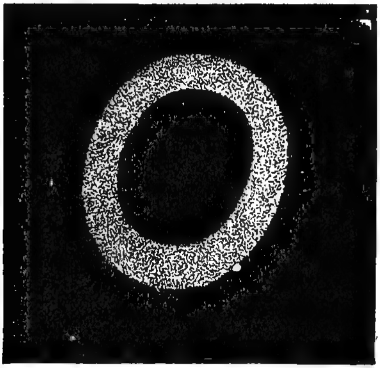
FIG. XIV.



TRANSITION FROM THE SPIRAL TO THE ANNULAR FORM.

such a system with the known laws of statics. Accurate measures are, therefore, of the highest interest for the pur-

FIG. XV.



ANNULAR NEBULA IN LYRA.

pose of showing whether actual rotation or other changes are taking place in these nebulæ; but, unfortunately, they

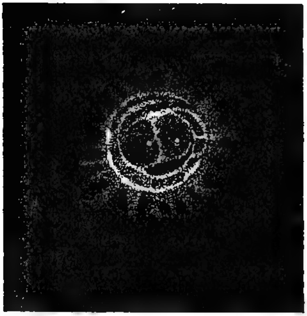
are rendered extremely difficult and uncertain by the want of outline, and by the remarkable faintness of these nebulous objects.

The transition state from the spiral to the annular form is shown in such nebulæ as the one represented in Fig. XIV.; and they then pass into the simple or compound annular nebula, of which a type is given in Fig. XV.

The space within most of these elliptic rings is not perfectly dark, but is occupied either by a diffused faint nebulous light, as in Fig. XV., or, as in most cases, by a bright nucleus, round which sometimes one ring, sometimes several, are disposed in various forms.

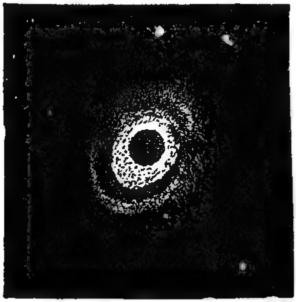
Those nebulæ which appear with tolerably sharply-defined

FIG. XVI.



Planetary Nebula with two Stars.

FIG. XVII.



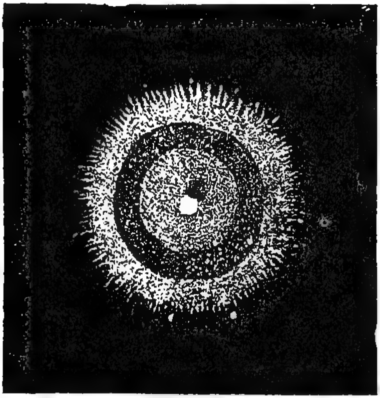
Planetary Nebula.

edges, in the form of a circle or slight ellipse, seem to belong to a much higher stage of development. From their resemblance to those planets which shine with a pale or bluish light, they have been called *planetary* nebulæ; in form, however, they vary considerably, some of them being spiral and some annular. Some of these planetary nebulæ are represented in Figs. XVI. and XVII. The first has two central stars or nuclei, each surrounded by a dark space, beyond which the spiral streaks are disposed; the second

is without a nucleus, but shows a well-defined ring of light.

The highest type of nebulæ are certainly the stellar nebulæ, in which a tolerably well defined bright star is surrounded by a completely round disk, or faint atmosphere of light, which sometimes fades away gradually into space, at other times terminates abruptly, with a sharp edge. Fig. XVIII. exhibits one of the most striking of these very remarkable stellar nebulæ. It is a veritable star of the eighth magnitude, and is not nebulous, but is surrounded by a

FIG. XVIII.



STELLAR NEBULA.

bright luminous atmosphere perfectly concentric. To the right of the star is a small dark space, such as often occurs in these nebulæ, indicating, perhaps, an opening in the surrounding atmosphere.

We have now passed in review nearly all that is at present known of the nebulæ, so far as their appearance and form have been revealed by the largest telescopes. The information as yet furnished by the spectroscope on this subject is certainly much less extensive, but is nevertheless of the

greatest importance, since the spectroscope has power to reveal the nature and constitution of these remote heavenly bodies. It must here again be remembered that the character of the spectrum not only indicates what the substance is that emits the light, but also its physical condition. If the spectrum be a *continuous* one, consisting of rays of every color or degree of refrangibility, then the source of light is either a *solid* or *liquid* incandescent body; if, on the contrary, the spectrum be composed of *bright lines* only, then it is certain that the light comes from *luminous gas;* finally, if the spectrum be continuous, but crossed by *dark* lines interrupting the colors, it is an indication that the source of light is a solid or liquid incandescent body, but that the light has passed through an atmosphere of vapors at a lower temperature, which, by their selective absorptive power, have abstracted those colored rays which they would have emitted had they been self-luminous.

When Huggins first directed his telespectroscope, in August, 1864, to one of these objects, a small but very bright nebula, he found, to his great surprise, that the spectrum, instead of being a continuous colored band, such as that given by a star, consisted only of *three bright lines.*

This one observation was sufficient to solve the long-vexed question, at least for this particular nebula, and to prove that it is not a cluster of individual, separable stars, *but is actually a gaseous nebula, a body of luminous gas.* In fact, such a spectrum could only be produced by a substance in a state of gas; the light of this nebula, therefore, was emitted neither by solid nor liquid incandescent matter, nor by gases in a state of extreme density, as may be the case in the sun and stars, but by *luminous gas in a highly rarefied condition.*

In order to discover the chemical nature of this gas, Huggins followed the usual methods of comparison, and tested the spectrum with the Fraunhofer lines of the solar spectrum, and the bright lines of terrestrial elements.

Besides the spectrum containing these three bright lines, the nebula gave also a very faint continuous spectrum, of scarcely perceptible width, which, from its nature, could proceed only from the diffused light of a faintly glowing nucleus, either solid or liquid, or from faintly luminous matter in the form of a cloud of solid or liquid particles.

All *planetary* nebulæ yield the same spectrum; the bright lines appear with considerable intensity in the spectroscope, and are of sufficient brilliancy to compare with the bright lines in the spectrum of a candle, although the nebulæ may not be brighter in the heavens than stars of the ninth magnitude. The reason of this is, that the light of the candle is spread out into a continuous spectrum, while that of the nebula remains concentrated into a few lines. The principle is identical with that by which the spectra of the solar prominences have been since observed in sunlight simultaneously with the greatly subdued spectrum of daylight.

During the years 1865 and 1866, more than sixty nebulæ were examined by Huggins with the spectroscope, mainly with the intention of ascertaining whether those which were clearly resolvable by the telescope into a cluster of bright points, gave a continuous spectrum, or one composed of bright lines.

As a result of his observations, Huggins divides the nebulæ into two groups:

1. The nebulæ giving a spectrum of one or more bright lines.

2. The nebulæ giving a spectrum apparently continuous.

About a third of the sixty nebulæ observed belong to the first group; their spectrum consists of one, two, or three bright lines; a few showing at the same time a very narrow, faint, continuous spectrum.

The great nebula of Orion (Fig. XII.) has been the subject of spectroscopic investigations. Its spectrum consists of three very conspicuous bright lines, one of which again indicates *nitrogen*, and another *hydrogen*.

Huggins has lately repeated his former observations with instruments of much greater power, and compared especially these two lines with those of the terrestrial gases, under circumstances which gave him a spectrum four times the length of the one he obtained in his earlier investigations. The result of these observations, continued for several nights, was to show the *complete coincidence*, even in this greatly extended spectrum of the nebular lines, with those of both gases, so that *there can be no remaining doubt as to the identity of the lines.*

Half of the nebulæ giving a *continuous* spectrum have been resolved into stars, and about a third more are probably resolvable; while of those yielding a spectrum of lines, *not one* has been certainly resolved by Lord Rosse. Considering the extreme difficulty attending investigations of this kind, there is scarcely any doubt that there is a complete accordance between the results of the telescope and spectroscope; *and therefore those nebulæ giving a continuous spectrum are clusters of actual stars*, while those giving a spectrum of bright lines must be regarded as *masses of luminous gas*, of which *nitrogen* and *hydrogen* form the chief constituents.

COMETS AND THEIR SPECTRA.

Besides the planets, which, already cold or in process of cooling, derive their light from the incandescent sun, round which they revolve in their appointed orbits, all travelling nearly in one plane among the fixed stars in regular progress from west to east, there appear from time to time certain other wandering stars of peculiar aspect, which, from their rapid change of form and size, their fantastic contour, and their brilliant light, usually excite the greatest attention; these remarkable visitors are comets; and though their laws of motion have been well ascertained, yet their physical constitution has presented greater difficulties to astronomers than even that of the nebulæ. When they first become vis-

ible, their motion is evidently round the sun, but frequently in orbits of such great elongation as hardly to be called elliptical, travelling, besides, in all possible planes and directions — sometimes, like the planets, from west to east, sometimes in the reverse way, from east to west. Several of these extraordinary objects move in closed orbits round the sun, with a regular period of revolution; others come quite unexpectedly from the regions of space into our system, and retreat again, to be seen no more. Some of the periodic comets are as follows: —

Comet.	Period.	Distance from the Sun. Perihelion.	Aphelion.
Encke's, .	$3\frac{1}{3}$ years.	289,000,000 miles.	350,000,000 miles.
Winnecke's,	$5\frac{1}{2}$ "	69,000,000 "	501,000,000 "
Brorsen's, .	$5\frac{3}{5}$ "	55,000,000 "	516,000,000 "
Biela's, . .	$6\frac{3}{4}$ "	78,000,000 "	564,000,000 "
Faye's, . .	$7\frac{1}{2}$ "	156,000,000 "	543,000,000 "
Halley's, .	$76\frac{1}{6}$ "	52,000,000 "	3,175,000,000 "

While these comets have but a short period, there are others, such as the comets of 1858, 1811, and 1844, the calculated periods of which amount respectively to 2,100, 3,000, and 100,000 years. Differences of quite a proportionate magnitude are observable, in relation to the points of nearest approach to and greatest distance from the sun. Encke's comet is twelve times nearer the sun at its perihelion than at its aphelion. Some of them, with an orbit extending beyond Jupiter, approach so close to the sun as almost to graze the surface. Newton estimated that the comet of 1680 came so near to the sun, that its temperature must have exceeded by two thousand times that of red-hot iron. At its nearest approach it was removed from the sun by only a sixth of his diameter. The comet of 1843, also, was so near the sun at its perihelion as to be seen in broad daylight.

Most comets exhibit a planetary disk, more or less bright, which is called the nucleus, and this is surrounded by a fainter cloudy or nebulous envelope, the coma; the nucleus

and coma form the head of the comet. In almost all comets visible to the naked eye, there streams out from the head a fan of light—the tail, consisting of one or more luminous streaks, which vary in width and length, are sometimes straight, sometimes curved, but almost always turned away from the sun, forming the prolongation of a straight line connecting the sun and the comet. While telescopic comets are usually without a tail, which causes them to assume the appearance of a more or less irregularly shaped nebula, possessing a nucleus, an example of which is given in Donati's comet, as it appeared when first seen on the 2d of June, 1858, the comet of July, 1861, exhibited two tails, and the comet of 1744 had even six.

Comets are transparent in every part, and cause no refraction in the light of the stars seen through them. Bessel saw a fixed star through Halley's comet, and Struve one through Biela's comet, when distant only a few seconds from the centre of the nucleus, which passed over the star in both instances without either rendering it invisible or even perceptibly fainter; from accurate measures taken at the time, and the calculated motion of the comet, it was evident that the position of the star had not been changed by any refraction of the light.

Similar observations were made with respect to Donati's comet of 1858, and the comet of July, 1861. Close to the head of the former, where the tail at its commencement was about 54,000 miles in thickness, Arcturus was seen to shine with undiminished brightness; while in both comets a number of fixed stars appeared in full brilliancy through even a much thicker portion of the tail. The comet of 1858 possessed a nucleus about 528,000 miles in diameter, and yet Struve saw a star of the eleventh magnitude through it—a fact which seems to justify the conclusion of Babinet, drawn from his own observations, that a comet has no influence upon the light of a star, and that stars of the tenth and eleventh magnitude, and some even fainter, may be seen

through their greatest mass, without losing in the smallest degree either their light or their color.

The tail is a prolongation of the coma, and is in most cases turned away from the sun, whether the comet be approaching or receding from the sun in the course of its orbit.

As a comet approaches the sun, the tail regularly increases, from which it appears that the sun, whether by the action of heat or other means, contributes essentially to the formation of the tail, and produces a separation of material particles from the head of the comet. The length of the tail is rarely less than 500,000 miles, and in some cases it extends as far as 100,000,000 or 150,000,000 miles. The breadth of the tail of the great comet of 1811, at its widest part, was nearly 14,000,000 miles, the length 116,000,000; and that of the second comet of the same year even 140,000,000 miles. And yet the formation of the tail takes place in a very short space of time, often in a few weeks, or even days.

The influence exercised on the formation of the tail by its approach to the sun was shown in the comet of 1680, for at its perihelion it travelled at the rate of 1,216,800 miles in an hour, and, as a consequence, put forth a tail in two days 54,000,000 miles in length.

It is easily conceivable that, under such circumstances, the mass of a comet must be exceedingly small. It is very probable that our earth actually passed, on the 30th of June, 1861, through part of the tail of the magnificent comet called the July comet, which suddenly appeared in the heavens, as if by magic, on the 29th of June, and no indication of such a contact was evinced, beyond a peculiar phosphorescence in the atmosphere, which was noticed by Mr. Hind, and also at the Liverpool Observatory. In the same way, the comet of 1776 passed among the satellites of Jupiter without disturbing their position in the slightest degree. This was not the case, however, with the comet, for the influence of the planet was so great on its small mass as to send it quite out

of its course, into an entirely new orbit, which it now accomplishes in about twenty years.

We must now consider the remarkable phenomenon of a comet being divided into two parts, each part becoming a separate comet, and pursuing an orbit of its own. Such an occurrence happened to Biela's comet while under observation in the year 1845. When observed on the 26th of November of that year, it appeared as a faint nebulous spot, not perfectly round, with an increased density towards the middle. On the 19th of December it was rather more elongated, and ten days later it had become divided into two separate, cloudy masses of equal dimensions, each furnished with a nucleus and tail, and for three months one followed the other at a distance of one tenth, subsequently one fifth, of the moon's diameter. The pair made their appearance again in August, 1852, after having travelled together in one common orbit round the sun for more than six years and a half; but the distance between them had much increased, and from 154,000 miles, it had now reached 1,404,000 miles. Nor is this all: in conformity with its known period, the return of this comet was expected in the year 1859, and again in 1866, when it must have been visible from the earth, as its path crossed the earth's orbit at the place where the earth was on the 30th of November. Notwithstanding the most diligent search, however, the comet could not be found, and it would seem that either, like Lexell's comet, it has been drawn out of its orbit by some member of the solar system, or else, as analogy suggests, it has ceased to be a comet, and has passed into some other form of existence.

We must enter a little further than might seem needful for our purpose into the important phenomena observed in comets, partly by the naked eye, but more especially by the telescope, in order to obtain some ground for answering queries as to the physical nature of these heavenly bodies, as well as to acquire a standard by which to compare the facts collected

by telescopic observation with those gathered by spectrum analysis.

These questions are directed, in the first place, to the consideration of whether comets, like fixed stars and nebulæ, are self-luminous, or whether, like planets, they shine by the reflected light of the sun; in the second place, to the consideration of their material composition and physical constitution. That the nucleus of a comet cannot be in itself a dark and solid body, such as the planets are, is proved by its great transparency; but this does not preclude the possibility of its consisting of innumerable solid particles, separated one from another, which, when illuminated by the sun, give by the reflection of the solar light the impression of a homogeneous mass. It has therefore been concluded that comets are either composed of a substance which, like gas in a state of extreme rarefaction, is perfectly transparent, or of small, solid particles, individually separated by intervening spaces, through which the light of a star can pass without obstruction, and which, held together by mutual attraction, as well as by gravitation towards a central denser conglomeration, moves through space like a cloud of dust. It is not impossible that comets without a nucleus are masses of gas at a white heat, of similar constitution to the nebulæ, while those possessing a nucleus are composed of disengaged solid particles. In any case, the connection lately noticed by Schiaparelli between comets and meteor showers seems to necessitate the supposition that in many comets a similar aggregation of particles exists.

Donati, at Florence, was the first to examine spectroscopically the light of comets: he compared the spectrum of the comet I., 1864, with the spectra of metals, in which the dark places were wider than the luminous parts, and he found that the entire spectrum consisted of three bright lines.

Tempel's comet was observed in January, 1866, by Secchi and Huggins, who found that it yielded a continuous spectrum exceedingly faint at the two ends, in which three bright

lines were seen by the former observer, and only one by Huggins. It appears from this, that the nucleus is at least *partially self-luminous*, and is composed of *gas in a luminous condition.* On the other hand, the continuous spectrum proves that some of the light is reflected sunlight, for it cannot be admitted that the coma is formed of incandescent solid or liquid particles.

The spectroscope gives no information as to the nature or condition of a substance from which we receive only reflected light; it is, however, probable that the coma and tail are of the same substance as the nucleus. These observations, therefore, yield no further result than that a gas in a state of luminosity is present in the comet, but that, at the same time, either from this gas or from other portions of the comet which are non-luminous, sunlight is also reflected.

Secchi's observations have been completely confirmed by those of Huggins. The spectrum of the comet consisted of three broad, bright bands, which were sharply defined at the edge towards the red, but faded away gradually on the opposite side.

It would be premature to draw decisive results from these comprehensive but as yet isolated observations. The spectrum of the three bright bands is derived unquestionably from the light of the comet's nucleus, and not from that of the coma, which is far too faint and ill-defined to produce such a spectrum; it may therefore be assumed that the nucleus is self-luminous, and that it is very possibly composed of glowing gas containing carbon.

By collating these various phenomena, the conviction can scarcely be resisted that the nuclei of comets not only emit their own light, *which is that of a glowing gas*, but also, together with the coma and the tail, reflect the light of the sun. There seems, therefore, nothing to contradict the theory that the mass of a comet may be composed of minute solid bodies, kept apart one from another in the same way as the infinitesimal particles forming a cloud of dust or

smoke are held loosely together, and that as the comet approaches the sun, the most easily fusible constituents of these small bodies become wholly or partially vaporized, and, in a condition of white heat, overtake the remaining solid particles, and surround the nucleus in a *self-luminous* cloud of glowing vapor. Spectrum analysis will not be able to afford any more certain evidence regarding the physical nature of comets until the appearance of a really brilliant comet, which can be examined in the various phases it may present.

It would lead us too far from our purpose, were we to describe more minutely the extremely interesting phenomena which the telescope has revealed of the separation of cometic matter, and the gradual formation of the coma and tail; nor can we enter more fully here into the causes of the changes produced in the form of a comet by its approach to the sun, or to one of the larger planets; but we cannot pass over the extremely ingenious hypothesis brought forward by Professor Tyndall, before the Philosophical Society of Cambridge, on the 8th of March, 1869. This admirable investigator had already proved, by a series of interesting experiments, that concentrated solar light, or the electric light, decomposes the volatile vapors of many liquids, producing almost instantly a precipitate of cloudy matter, in which some very peculiar phenomena of light are displayed. The quantity of vapor may be so small as to escape detection, but the concentrated light falling upon it soon forms a blue cloud from the moving atoms of vapor which now become visible, and appear, according to the nature of the vapor, in a variety of forms, as precipitations of matter on the beams of light.

It is very striking, in this experiment, to see the astonishing amount of light that an infinitesimal amount of decomposable vapor is able to reflect. When the electric light is admitted into the tube, nothing is to be seen for the first moment; but soon a blue cloud shows itself, which is

formed of almost infinitely small particles, either of vapor, or, what is more probable, of the molecules set free by its decomposition, and after some minutes the whole tube is filled with this blue color. The vaporous particles gradually augment in magnitude, and after some time (from ten to fifteen minutes) a dense white cloud fills the tube, which discharges so great a body of light that it is scarcely conceivable how so small a quantity of matter can possibly reflect so much light.

"Nothing," says Tyndall, "could more perfectly illustrate that 'spiritual texture' which Sir John Herschel ascribes to a comet, than these actinic clouds. Indeed, the experiments prove that matter of almost infinite tenuity is competent to shed forth light far more intense than that of the tails of comets."

FALLING STARS, METEOR SHOWERS, BALLS OF FIRE, AND THEIR SPECTRA.

Whoever has observed the heavens on a clear night with some amount of attention and patience, cannot fail to have noticed the phenomenon of a falling star, one of those well-known fiery meteors which suddenly blaze forth in any quarter of the heavens, descend towards the earth, generally with great rapidity, in either a vertical or slanting direction, and disappear after a few seconds at a higher or lower altitude. As a rule, falling stars can only be seen of an evening, or at night, owing to the great brightness of daylight; but many instances have occurred in which their brilliancy has been so great as to render them visible in the daytime, as well when the sky was overcast as when it was perfectly cloudless. It has been calculated that the average number of these meteors passing through the earth's atmosphere, and sufficiently bright to be seen at night with the naked eye, is not less than seven million and a half during the space of twenty-four hours; and this number must be increased to *four hundred million*, if those be included which a tele-

scope would reveal. In many nights, however, the number of these meteors is so great, that they pass over the heavens like flakes of snow, and for several hours are too numerous to be counted. Early in the morning of the 12th of November, 1799, Humboldt and Bonpland saw before sunrise, when on the coast of South America, thousands of meteors during the space of four hours, most of which left a track behind them of from 5° to 10° in length; they mostly disappeared without any display of sparks, but some seemed to burst, and others, again, had a nucleus as bright as Jupiter, which emitted sparks. On the 13th of November, 1833, there fell another shower of meteors, in which, according to Arago's estimation, two hundred and forty thousand passed over the heavens, as seen from the place of observation, in three hours.

Only in very rare instances do these fiery substances fall upon the surface of the earth; when they do, they are called balls of fire; and occasionally they reach the earth before they are completely burnt out or evaporated; they are then termed meteoric stones, aerolites, or meteoric iron. They are also divided into accidental meteors and meteoric showers, according as to whether they traverse the heavens in every direction at random, or appear in great numbers following a common path, thus indicating that they are parts of a great whole.

It is now generally received, and placed almost beyond doubt by the recent observations of Schiaparelli, Le Verrier, Weiss, and others, that these meteors, for the most part small, but weighing occasionally many tons, are fragmentary masses, revolving, like the planets, round the sun, which in their course approach the earth, and, drawn by its attraction into our atmosphere, are set on fire *by the heat generated through the resistance offered by the compressed air.*

The chemical analysis of those meteors which have fallen to the earth in a half-burnt condition in the form of meteoric stones, proves that they are composed only of terrestrial ele-

ments, which present a form and combination commonly met with in our planet. Their chief constituent is metallic iron, mixed with various silicious compounds; in combination with iron, nickel is always found, and sometimes also cobalt, copper, tin, and chromium; among the silicates, olivine is especially worthy of remark as a mineral very abundant in volcanic rocks, as also augite. There have also been found in the meteoric stones hitherto examined, oxygen, hydrogen, sulphur, phosphorus, carbon, aluminium, magnesium, calcium, sodium, potassium, manganese, titanium, lead, lithium, and strontium.

The height at which meteors appear is very various, and ranges chiefly between the limits of forty-six and ninety-two miles. The mean may be taken at sixty-six miles. The speed at which they travel is also various, generally about half as fast again as that of the earth's motion round the sun, or about twenty-six miles in a second: the maximum and minimum differ greatly from this amount, the velocity of some meteors being estimated at fourteen miles, and that of others at one hundred and seven miles in a second.

When a dark meteorite of this kind, having a velocity of one thousand six hundred and sixty miles per minute, encounters the earth, flying through space at a mean rate of one thousand one hundred and forty miles per minute, and when through the earth's attraction its velocity is further increased two hundred and thirty miles per minute, this body meets with such a degree of resistance, even in the highest and most rarefied state of our atmosphere, that it is impeded in its course, and loses in a very short time a considerable part of its momentum. By this encounter there follows a result common to all bodies which, while in motion, suddenly experience a check. When a wheel revolves very rapidly, the axletree or the drag which is placed under the wheel is made red hot by the friction. When a cannon ball strikes suddenly with great velocity against a plate of iron, which constantly happens at target practice, a spark is seen

to flash from the ball, even in daylight; under similar circumstances, a lead bullet becomes partially melted. The heat of a body consists in the *vibratory motion of its smallest particles;* an increase of this molecular motion is synonymous with a higher temperature; a lessening of this vibration is termed decreasing heat, or the process of cooling. Now, if a body in motion — as, for instance, a cannon ball — strike against an iron plate, or a meteorite against the earth's atmosphere, in proportion as the motion of the body diminishes, and the external action of the moving mass becomes annihilated by the pressure of the opposing medium upon the foremost molecules, the vibration of these particles increases; this motion is immediately communicated to the rest of the mass, and by the acceleration of this vibration through all the particles, the temperature of the body is raised. This phenomenon, which always takes place when the motion of a body is interrupted, is designated by the expression *the conversion of the motion of the mass into molecular action or heat;* it is a law without exception, that where the *external* motion of the mass is diminished, an inner action among its particles, or heat, is set up in its place as an equivalent, and it may be easily supposed that even in the highest and most rarefied strata of the earth's atmosphere, the velocity of the meteorite would be rapidly diminished by its opposing action, so that, shortly after entering our atmosphere, the vibration of the inner particles would become accelerated to such a degree as to raise them to a white heat, when they would either become partially fused, or, if the meteorite were sufficiently small, it would be dissipated into vapor, and leave a luminous track behind it of glowing gas.

Haidinger, in a theory embracing all the phenomena of meteorites, explains the formation of a ball of fire round the meteor by supposing that the meteorite, in consequence of its rapid motion through the atmosphere, presses the air before it till it becomes luminous. The compressed air in

which the solid particles of the surface of the meteorite glow then rushes on all sides, but especially over the surface of the meteor behind it, where it encloses a pear-shaped vacuum which has been left by the meteorite, and so appears to the observer as a ball of fire. If several bodies enter the earth's atmosphere in this way at the same time, the largest among them precedes the others, because the air offers the least resistance to its proportionately smallest surface; the rest follow in the track of the first meteor, which is the only one surrounded by a ball of fire. When, by the resistance of the air, the motion of the meteor is arrested, it remains for a moment perfectly still; the ball of fire is extinguished, the surrounding air rushes suddenly into the vacuum behind the meteor, which, left solely to the action of gravitation, falls vertically to the earth. The loud, detonating noise usually accompanying this phenomenon finds an easy explanation in the violent concussion of the air behind the meteor, while the generally received theory that the detonating noise is the result of an explosion or bursting of the meteorite, does not meet with any confirmation.

The circumstance that most meteors are extinguished before reaching the earth seems to show that their mass is but small; but this is not always the case. If the distance of a meteor from the earth be ascertained, as well as its apparent brightness as compared with that of a planet, it is possible, by comparing its luminosity with that of a known quantity of ignited gas, to estimate the degree of heat evolved in the meteor's combustion. As this heat originates from the motion of the meteor being impeded or interrupted by the resistance of the air, and as this motion or momentum is exclusively dependent on the speed of the meteor, as well as upon its mass, it is possible, when the rate of motion has been ascertained by direct observation, to determine the mass. Professor Alexander Herschel has calculated, by this means, that those meteors of the 9th and 10th of August, 1863, which equalled the brilliancy of Venus and Jupiter,

must have possessed a mass of from five to eight pounds, while those which were only as bright as stars of the second or third magnitude would not be more than about ninety grains in weight. As the greater number of meteors are less bright than stars of the second magnitude, the faint meteors must weigh only a few grains; for according to Professor Herschel's computation, the five meteors observed on the 12th of November, 1865, some of which surpassed in brilliancy stars of the first magnitude, had not an average weight of more than five grains; and Schiaparelli estimated the weight of a meteor from other phenomena to be about fifteen grains. The mass, however, of the meteoric stones which fall to the earth is considerably greater, whether they consist of one single piece, such as the celebrated iron-stone discovered by Pallas in Siberia, which weighed about two thousand pounds, and the meteorites of the Mexican desert,*

* THE METEORITES OF THE MEXICAN DESERT. — With the object of fixing with greater precision the geographical position of the meteoric masses that have been from time to time met with on the Bolson de Mapini, Dr. J. Lawrence Smith has communicated a paper to the *American Journal of Science* for November, 1871, 335. There were already known the Cohahuila meteorite of 1854 (1), the Cohahuila meteorite of 1868 (2), the Chihuahua iron of 1854 (3), still at the *Hacienda de Conception*, and weighing about four thousand pounds, and the Tucson iron (4), found in 1854 on the north of the Rio Grande, and having the form of a ring. This mass weighs from two to three thousand pounds. A fifth mass (5) has since been heard of on the western border of the Mexican desert, that has received the name of the *San Gregario meteoric iron*. It measures six feet six inches in length, is five feet six inches high, and four feet thick at the base. On one part of its surface, 1821 has been cut with a chisel. Its weight is calculated to be about five tons. An examination of a fragment showed it to be one of the softer meteoric irons. It has a specific gravity of 7.84, and consists of ninety-five per cent. of iron, and five per cent. of nickel, inclusive of a little cobalt. Still more recently, news has arrived of the discovery, in the central portion of the desert, of a huge meteorite (6), larger than any yet found in this locality. Dr. Lawrence Smith's paper is illustrated with a little map, indicating their rel-

or of a cloud composed of many small bodies, which penetrate the earth's atmosphere in parallel paths, and which, from a simultaneous ignition and descent upon the earth, present the appearance of a large meteor bursting into several smaller pieces. Such a shower of stones, accompanied by a bright light and loud explosion, occurred at L'Aigle, in Normandy, on the 26th of April, 1803, when the number of stones found in a space of fourteen square miles exceeded two thousand. In the meteoric shower that fell at Kúyahinga, in Hungary, on the 9th of June, 1866, the principal stone weighed about eight hundred pounds, and was accompanied by about a thousand smaller stones, which were strewed over an area of nine miles in length by three and one quarter broad.

It must not be supposed, however, that the density of such a cosmical cloud is as great, when out of the reach of the attraction of the sun and the earth, as when its constituents fall upon the earth's surface. Schiaparelli calculates, from the number of meteors observed yearly in the month of August, that the distance between any two must amount, on the average, to four hundred and sixty miles. As the cosmical clouds which produce the meteors approach the sun in their wanderings from the far-off regions of space, they increase in density some million times; therefore the distance between any two meteors, only a few grains in weight, before the cloud begins to be condensed, may be upwards of forty thousand miles.

The most striking example of such a cosmical cloud, composed of small bodies loosely hung together, and existing

ative positions. He believes they are the result of two falls. The Tucson iron has characters that distinguish it from the remaining five. The latter, he considers, fell at an epoch probably far remote, moving from north-west to south-west during their descent. 1 and 2 fell first, 85 miles apart. The distances between the larger masses are, — from 2 to 6, 135 miles; from 6 to 5, 165 miles; and from 5 to 3, about 90 miles

with hardly any connection one with another, is exhibited in the meteoric showers occurring periodically in August and November. It is an ascertained fact that, on certain nights in the year, the number of meteors is extraordinarily great, and that at these times they shoot out from certain fixed points in the heavens. The shower of meteors which happens every year on the night of the 10th of August, proceeding from the constellation of Perseus, is mentioned in many old writings. The shower of the 12th and 13th of November occurs periodically every thirty-three years, for three years in succession, with diminishing numbers; it was this shower that Alexander Von Humboldt and Bonpland observed on the 13th of November, 1799, as a real rain of fire. It recurred on the 12th of November, 1833, in such force that Arago compared it to a fall of snow, and was lately observed again in its customary splendor in North America, on the 14th of November, 1867. Besides these two principal showers, there are almost a hundred others, recurring at regular intervals; each of these is a cosmical cloud, composed of small, dark bodies, very loosely held together, like the particles of a sand cloud, which circulate round the sun in one common orbit. The orbits of these meteor streams are very diverse; they do not lie approximately in one plane, like those of the planets, but cross the plane of the earth's orbit at widely different angles. The motion of the individual meteors ensues in the same direction in one and the same orbit; but this direction is in some orbits in conformity with that of the earth and planets, while in others it is in the reverse order.

The earth, in its revolution round the sun, occupies every day a different place in the universe; if, therefore, a meteoric shower pass through our atmosphere at regular intervals, there must be at the place where the earth is at that time an accumulation of these small cosmical bodies, which, attracted by the earth, penetrate its atmosphere, are ignited by the resistance of the air, and become visible as falling

stars. A cosmical cloud, however, cannot remain at a fixed spot in our solar system, but must circulate round the sun as planets and comets do; whence it follows that the path of a periodic shower intersects the earth's orbit, and the earth must either be passing through the cloud, or else very near to it, when the meteors are visible to us.

The meteor shower of the 10th of August, the radiant point of which is situated in the constellation of Perseus, takes place nearly every year, with varying splendor; we may therefore conclude that the small meteors composing this group form a ring round the sun, and the earth every 10th of August is at the spot where this ring intersects our orbit; also that the ring of meteors is not equally dense in all parts: here and there these small bodies must be very thinly scattered, and in some places even altogether wanting.

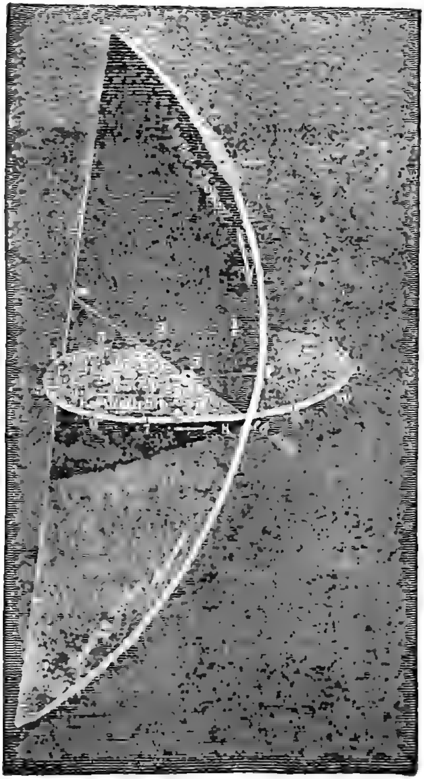
Fig. XIX. shows a very small part of the elliptic orbit which this meteoric mass describes round the sun S. The earth encounters this orbit on the 10th of August, and goes straight through the ring of meteors. The dots along the ring indicate the small, dark meteors which ignite in our atmosphere, and are visible as shooting stars. The line *m* is the line of intersection of the earth's orbit and that of the meteors; the line P S shows the direction of the major axis of their orbit. This axis is fifty times greater than the mean diameter of the earth's orbit; the orbit of the meteors is inclined to that of the earth at an angle of 64° 3′, and their motion is retrograde, or contrary to that of the earth.

The November shower is not observed to take place every year on the 13th or 14th of that month, but it is found that every thirty-three years an extraordinary shower occurs on those days, proceeding from a point in the constellation of Leo. The meteors composing this shower, unlike the August one, are not distributed along the whole course of their orbit, so as to form a ring entirely filled with meteoric particles, but constitute a dense cloud, of an elongated form, which completes its revolution round the sun in thirty-three

years, and crosses the earth's path at that point where the earth is every 14th of November.

When the November shower reappears after the lapse of

FIG. XIX.



ORBIT OF THE METEOR SHOWER OF THE 10th OF AUGUST.

thirty-three years, the phenomenon is repeated during the two following years on the 14th of that month, but with diminished splendor; the meteors, therefore, extend so far

along the orbit as to require three years before they have all crossed the earth's path at the place of intersection; they are, besides, unequally distributed, the preceding part being much the most dense.

A very small part of the elliptic orbit, and the distribution of the meteors during the November shower, is represented in Fig. XX. As shown in the drawing, this orbit intersects that of the earth at the place where the earth is about the 14th of November, and the motion of the meteors, which occupy only a small part of their orbit, and are very unequally distributed, is retrograde, or contrary to that of the earth. The inclination of this orbit to that of the earth is only 17° 44′; its major axis is about ten and one third times greater than the diameter of the earth's orbit, and the period of revolution for the densest part of the meteorites round the sun S is thirty-three years three months.

From all we have now learned concerning the nature and constitution of comets, nebulæ, cosmical clouds, and meteoric swarms, an unmistakable resemblance will be remarked among these different forms in space. The affinity between comets and meteors had been already recognized by Chladni, but Schiaparelli, of Milan, was the first to take account of all the phenomena exhibited by these mysterious heavenly bodies, and with wonderful acuteness to treat successfully the mass of observations and calculations which had been contributed during the course of the last few years by Oppolzer, Peters, Bruhns, Heis, Le Verrier, and other observers. He not only shows that the orbits of meteors are quite coincident with those of comets, and *that the same object may appear to us at one time as a comet and at another as a shower of meteors*, but he proves also, by a highly elegant mathematical calculation, that the scattered cosmical masses known to us by the name of nebulæ would, if in their journey through the universe they were to come within the powerful attraction of our sun, be formed into comets, and these again into meteoric showers.

The following is a short statement of Schiaparelli's theory. Nebulæ are composed of cosmical matter, in which, as yet, there is no central point of concentration, and which has not become sufficiently dense to form a celestial body, in the ordinary sense of the term. The diffuse substance of these cosmical clouds is very loosely hung together; its particles are widely separated, thus constituting masses of enormous extent, some of which have taken a regular form, and some not. As these nebulous clouds may be supposed to have, like our sun, a motion in space, it will sometimes happen that such a cloud comes within reach of the power of attraction of our sun. The attraction acts more powerfully on the preceding part of the nebula than on the further and following portion; and the nebula, while still at a great distance, begins to lose its original spherical form, and becomes considerably elongated. Other portions of the nebulous mass follow continuously the preceding part, until the sphere is converted into a long cylinder, the foremost part of which, that towards the sun, is denser and more pointed than the following part, which retains a portion of its original breadth. As it nears the sun, this transformation of the nebulous cloud becomes more complete: illuminated by the sun, the preceding part appears to us as a dense nucleus, and the following part, turned away from the sun, as a long tail, curved in consequence of the lateral motion preserved by the nebula during its progress. Out of the original spherical nebula, quite unconnected with our solar system, a comet has been formed, which, in its altered condition, will either pass through our system, to wander again in space, or else remain as a permanent member of our planetary system. The form of the orbit in which it moves depends on the original speed of the cloud, its distance from the sun, and the direction of its motion, and thus its path may be elliptical, hyperbolical, or parabolical; in the last two cases, the comet appears only once in our system, and then returns to wander in the realms of space; in the former case, it abides

with us, and accomplishes its course round the sun, like the planets, in a certain fixed period of years. From this it is evident that the orbits of comets may occur at every possible angle to that of the earth, and that their motion will be sometimes progressive and sometimes retrograde.

The history of the cosmical cloud does not, however, end with its transformation into a comet. Schiaparelli shows in a striking manner that, as a comet is not a solid mass, but consists of particles each possessing an independent motion, the head or nucleus nearer the sun must necessarily complete its orbit in less time than the more distant portions of the tail. The tail will therefore lag behind the nucleus in the course of the comet's revolution, and the comet, becoming more and more elongated, will at last be either partially or entirely resolved into a ring of meteors. In this way, the whole path of the comet becomes strewn with portions of its mass, — with those small, dark, meteoric bodies which, when penetrating the earth's atmosphere, become luminous, and appear as falling stars. Instead of the comet, there now revolves round the sun a broad ring of meteoric stones, which occasion the phenomena we every year observe as the August meteors. Whether this ring be continuous, and the meteoric masses strewn along the whole course of the path of the original comet, or whether the individual meteors, as in the November shower, have not filled up entirely the whole orbit, but are still partially in the form of a comet, is in the transformation of a cosmical cloud through the influence of the sun only a question of time; in course of years, the matter composing a comet which describes an orbit round the sun must be dispersed over its whole path; *if the original orbit be elliptical, an elliptic ring of meteors will gradually be formed from the substance of the comet, of the same size and form as the original orbit.*

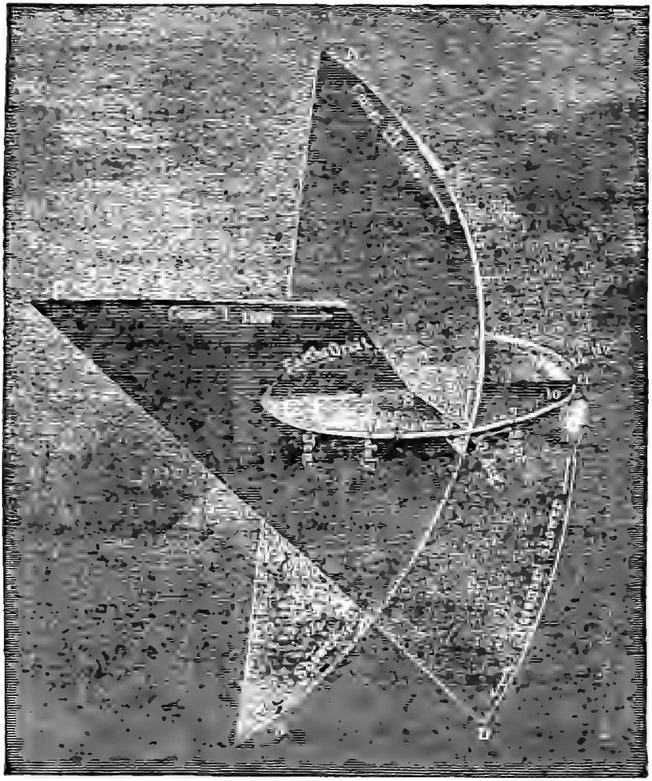
Schiaparelli has in fact discovered so close a resemblance between the path of the August meteors and that of the comet of 1862, No. III., that there cannot be any doubt as

to their complete identity. The meteors to which we owe the annual display of falling stars on the 10th of August are not distributed equally along the whole course of their orbit; it is still possible to distinguish the agglomeration of meteoric particles which originally formed the cometary nucleus from the other less dense parts of the comet; thus in the year 1862, the denser portion of this ring of meteors, through which the earth passes annually on the 10th of August, and which causes the display of falling stars, was seen in the form of a comet, with head and tail as the densest parts, approached the sun and earth in the course of that month. Oppolzer, of Vienna, calculated with great accuracy the orbit of this comet, which was visible to the naked eye. Schiaparelli had previously calculated the orbit of the meteoric ring, to which the shooting stars of the 10th of August belong before they are drawn into the earth's atmosphere. The almost perfect identity of the two orbits justifies Schiaparelli in the bold assertion that *the comet of* 1862, No. III., *is no other than the remains of the comet out of which the meteoric ring of the* 10*th of August has been formed in the course of time.* The difference between the comet's nucleus and its tail, that has now been formed into a ring, consists in that while the denser meteoric mass forming the head approaches so near the earth once in every hundred and twenty years as to be visible in the reflected light of the sun, the more widely scattered portion of the tail composing the ring remains invisible, even though the earth passes through it annually on the 10th of August. Only fragments of this ring, composed of dark meteoric particles, become visible as shooting stars when they penetrate our atmosphere by the attraction of the earth, and ignite by the compression of the air.

A cloud of meteors of such a character can naturally only be observed as a meteor shower when in the nodes of its orbit, — that is to say, in those points where it crosses the earth's orbit, — and then only when the earth is also there at

the same time, so that the meteors pass through our atmosphere. The nebula coming within the sphere of attraction

FIG. XX.



Orbits of the August and November Meteor Showers.
(Orbits of Comets III., 1862, and I., 1866.)

of our solar system, would, at its nearest approach to the sun (perihelion), and in the neighboring portions of its orbit,

appear as a *comet*, and when it grazed the earth's atmosphere would be seen as a *shower of meteors*.

Calculation shows that this ring of meteors is about ten thousand nine hundred and forty-eight millions of miles in its greatest diameter. As the meteoric shower of the 10th of August lasts about six hours, and the earth travels at the rate of eighteen miles in a second, it follows that the breadth of this ring, at the place where the earth crosses it, is four million forty-three thousand five hundred and twenty miles. In Fig. XX., A B represents a portion of the orbit of the comet of 1862, No. III., which is identical with that (Fig. XIX.) of the August shower.

The calculations of Schiaparelli, Oppolzer, Peters, and Le Verrier have also discovered the comet producing the meteors of the November shower, and have found it in the small comet of 1866, No. I., first observed by Tempel, of Marseilles. Its transformation into a ring of meteors has not proceeded nearly so far as that of the comet of 1862, No. III. Its existence is of a much more recent date; and therefore the dispersion of the meteoric particles along the orbit, and the consequent formation of the ring, is but slightly developed.

According to Le Verrier, a cosmical nebulous cloud entered our system in January 126, and passed so near the planet Uranus as to be brought by its attraction into an elliptic orbit round the sun. This orbit is the same as that of the comet discovered by Tempel, and calculated by Oppolzer, and is identical with that in which the November group of meteors make their revolution.

Since that time, this cosmical cloud, in the form of a comet, has completed fifty-two revolutions round the sun, without its existence being otherwise made known than by the loss of an immense number of its components, in the form of shooting stars, as it crossed the earth's path in each revolution, or in the month of November in every thirty-three years. It was only in its last revolution, in the year

1866, that this meteoric cloud, now forming part of our solar system, was first seen as a comet.

The orbit of this comet is much smaller than that of the August meteors, extending at the aphelion as far as the orbit of Uranus, while the perihelion is nearly as far from the sun as our earth. The comet completes its revolution in about thirty-three years and three months, and encounters the earth's orbit as it is approaching the sun towards the end of September. It is followed by a large group of small meteoric bodies, which form a very broad and long tail, through which the earth passes on the 14th of November. Those particles which come in contact with the earth, or approach so near as to be attracted into its atmosphere, become ignited, and appear as falling stars. As the earth encounters the comet's tail, or meteoric shower, for three successive years at the same place, we must conclude the comet's track to have the enormous length of seventeen hundred and seventy-two millions of miles. In Fig. XX., C D represents a portion of the orbit of this comet, which is identical with the orbit of the November meteors.

By the side of these important conclusions, which the observation and acuteness of modern astronomers have been able to make concerning the nature and mutual connection of nebulæ, comets, meteors, and balls of fire, the results of spectrum analysis, as applied to meteors, will seem to be exceedingly scant. This is easy to understand when we reflect how rapidly these fiery meteors rush through our atmosphere, and how difficult it is to lay hold of them with the spectroscope during their instantaneous apparition. Before the instrument can be directed to a meteor or ball of fire, and the focus adjusted, the object has disappeared from view. The application, therefore, of spectrum analysis to these fleeting visitors is left almost entirely to chance, and is mainly confined to those nights in which yearly, or at certain known periods, an extraordinary shower of falling stars is expected to occur.

The principal result of the investigations thus far made is confined, therefore, to the establishment of the fact that meteors consist of *incandescent solid bodies*, and that a difference is discernible in the chemical composition of the August and November meteoric showers.

The November shower of 1868 was observed by Secchi. Among the numerous meteors that left a train of light behind them, was one, the track of which lasted fifteen minutes, and was at first sufficiently bright to allow of examination by a prism. Secchi found the spectrum to be discontinuous, and the principal bright bands and lines were red, yellow, green, and blue. Besides this observation, Secchi was so fortunate as to see two meteors in the spectroscope: the magnesium line appeared with great distinctness, besides which some lines were also seen in the red.

On account of the great difficulty of observing meteors with a narrow setting of the slit, ordinary spectroscopes are not suited to this purpose. The only resource, therefore, is to substitute a cylindrical lens for the slit. There can be no doubt, however, that an apparatus will be invented which will be employed in future with great success in the investigation of meteors by means of spectrum analysis.

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7. Corals and Coral Islands.

IN the following article we shall endeavor to give our readers some slight insight into the growth and structure of coral reefs and islands, by illustrations and quotations, taken from Prof. J. D. Dana's recent and exhaustive work on the subject. Our only hope is, to awaken an interest in the subject which will induce our readers to examine carefully this beautiful and instructive volume. In our limited space we can only give a few of the most characteristic features connected with the subject. [ED.

A singular degree of obscurity has possessed the popular mind with regard to the growth of corals and coral reefs, in consequence of the readiness with which speculations have been supplied and accepted in place of facts; and to the present day, the subject is seldom mentioned without the qualifying adjective *mysterious*, expressed or understood. Science, while it penetrates deeply the system of things about us, sees everywhere, in the dim limits of vision, the word *mystery*. Surely there is no reason why the simplest of organisms should bear the impress most strongly. It is not more surprising, nor a matter of more difficult comprehension, that a polyp should form structures of stone (carbonite of lime), called coral, than that the quadruped should form its bones, or the mollusk its shell.

The processes are similar, and so is the result. In either case, it is a simple animal secretion. The power of secretion is, then, one of the *first* and most common of those that belong to living tissues. It belongs evidently to the lowest kind of life. These are the best stone-makers; for in the simplicity of their structure they may be almost all stone, and still carry on the processes of nutrition and growth.

Coral is made by organisms of four very different kinds.

These are: *First.* POLYPS, the most important of coral-making animals, the principal source of the coral reefs of the world. *Second.* Animals related to the little Hydra of fresh waters, and called HYDROIDS, which, as Agassiz has shown, form the very common and often large corals called Millepores. *Third.* The lowest tribe of Mollusks, called BRYOZOANS, which produce delicate corals, sometimes branching and moss-like. *Fourth.* Algæ, or sea-weeds.

POLYPS. A good idea of a polyp may be had from comparison with the garden aster; for the likeness to many of them, in external form, as well as delicacy of coloring, is singularly close. The polyp flower has a disk fringed around with petal-like organs called tentacles, which answer to the petals of the aster. Below the disk there is a stout cylindrical body, which contains the stomach and internal cavity. Here the flower-animal and garden-flower diverge in character, the difference being required by the different modes of nutrition, and other characteristics in the two kingdoms of nature. The coral polyp is as much an animal as a cat or dog.

The highest of Actinoid Polyps are those of the *Actinia Tribe* — the species that secrete no coral to clog vital action and prevent locomotion. The details of structure may be best described from the Actinia or Sea-anemone, and afterwards the distinguishing characters of the coral-making polyps may be mentioned. In external aspect, and in internal characters, *all* are essentially identical.

The external parts of an Actinia are, a sub-cylindrical body; a disk at top; one or more circular series of tentacles, making a border to the disk; a mouth — a merely fleshy, toothless opening, at the centre of the disk; a basal disk for attachment. They vary greatly in color, and while often brilliantly colored, especially in the tropics, others are nearly colorless. They vary in size from an eighth of an inch in diameter to fourteen inches.

The *internal structure* of the Actinia is radiate, like the

external. The mouth opens directly into a stomach, which descends usually about a third of the way to the base of the body; its sides are closed together unless it be in use. The general cavity of the body around and below the stomach is divided radiately by fleshy partitions, or septa, into narrow compartments, the larger of which connect the stomach to the sides of the animal, and, besides holding it in place, serve to distend it for the reception of food. The mouth and stomach are very easily extended, so that an Actinia may swallow an animal nearly as large as itself; it gradually stretches the margins of the mouth over the mollusk or crab, until the whole is enclosed, and passed into the digestive sac; and when digestion is complete, the shell and any other refuse matters are easily got rid of by reversing the process.

But the Actinia owes nearly all its powers of attack to its *lasso-cells*, of which it has myriads, which it can dart out with lightning-like rapidity when needed, and which pierce and *poison* the ill-fated mollusk or crab which the waves throw within its reach.

Reproduction is carried forward both by ova and by buds, though the *latter* method is mostly confined to the coral-making polyps.

The ova have no chance of escape, except through the stomach and mouth. They are covered with vibratile cilia, and rove about free for a while. As the development goes forward, a depression begins at one end, which deepens and becomes a stomach, with the entrance to it as a mouth.

In the budding process, Actiniæ grow young ones on their sides, near the margin of the base. A protuberance begins to rise, and soon shows a mouth, and then becomes surrounded by tentacles, and finally separates from the parent, an independent animal. These polyps have the faculty of reproducing lost parts, and to such an extent that a mere fragment, if it be from the lower part, and include a portion of the base, will reproduce all the rest of the Actinia, even to the disk, tentacles, and stomach.

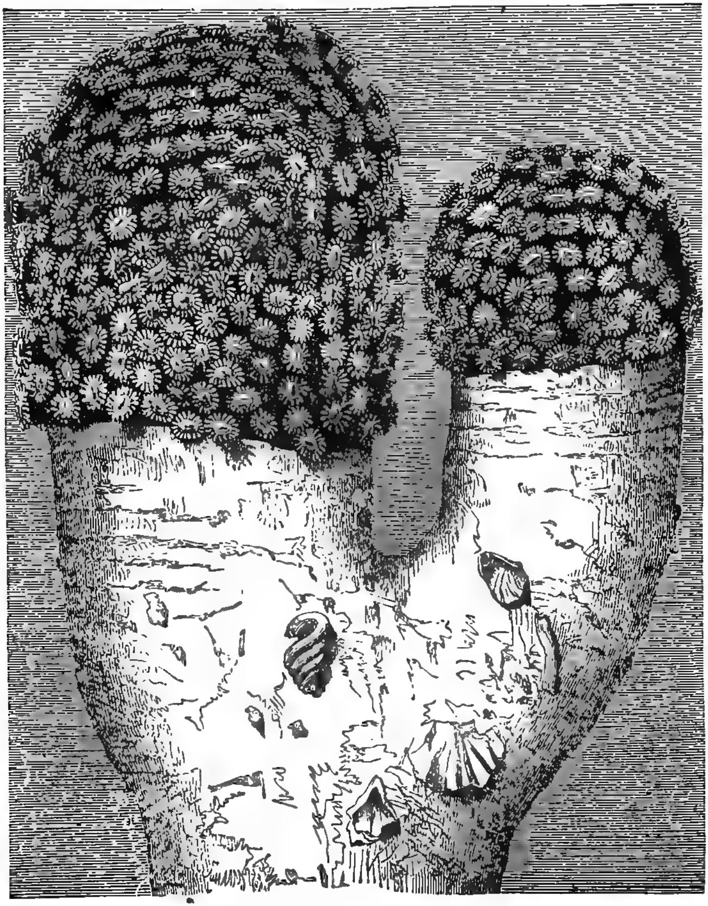
CORAL-MAKING POLYPS. — Of their form, tentacles, mouth, stomach, fleshy septa, lasso-cells, food, digestion, and respiration, nothing need be said, these characteristics being the same as in the Actinia or Sea Anemones just described. Their striking peculiarities depend upon the secretion of coral, making them a fixed species, and involving an absence of the base, and in the case of a majority of the species, on the extent to which they multiply by buds in imitation of species in the vegetable kingdom.

The coral skeleton which the secretions of polyps form is called the *corallum*. The secretions take place among the tissues of the sides and lower part of the polyp, but never in the disk or stomach, as this would interfere with the functions of these organs.

Where great numbers of polyps are connected together, they form what is called a zoöphyte or zoöthóme, which is literally a *heap* of *animal life*, a result, in part, of the process of budding already described. Since in these species the young does not separate from the parent, this budding produces a compound group, composed of thousands, and in some cases hundreds of thousands, from a single germ. The several polyps have separate mouths, tentacles, and stomachs; but beyond this there is no individual property. The zoöthome, or zoöphyte, is like a living sheet of animal matter, fed and nourished by numerous mouths and as many stomachs.

Sometimes the first polyp gives out buds from its sides, and continues to do so when it grows upward, and thus a rising stem is formed, with one parent polyp at the top of it, and one at the extremity of each branch, and a little tree is produced. In other cases, the budding goes on until a cluster of some size is formed, and then the older or marginal polyps cease budding, while the rest continue the process, and in this way a stem rises, in which death and life are going on together *pari passu*. Fig. XXI. represents a case of this kind, in which a large column of coral is in process

Fig. XXI.



COLUMN OF LIVING AND DEAD CORAL.

of formation. This condition of growth is favored by the coral secretions; for they give the polyp a chance to mount upwards on the coral, as it lengthens it by secretions at the

top. But, to be successful in this ascending process, either the polyp must have the power of indefinite elongation, or it must desert the lower part of the corallum as growth goes forward, and this last is what happens. With such a mode of increase, there is no necessary limit to the growth of zoöphytes. The rising column may grow upward indefinitely, until it reaches the surface of the sea, and then death ensues simply from exposure, and not from any failure in its powers of life.

The death of the polyps about the base of a coral tree, would expose it, seemingly, to immediate wear from the waters around it, especially as the texture is usually porous. But nature is not without an expedient to prevent, to some extent, this catastrophe. There is often an outer impervious layer of carbonate of lime, secreted by the lower edge of the series of dying polyps, as is seen in Fix. XXI. Then, further, the dead surface becomes the resting-place of numberless small incrusting species of corals and mollusks. The older polyps, before death, often increase their coral secretions from within, filling the pores as the tissues occupying them dwindle, and thus render the corallum nearly solid. The breaking of a branch is no serious injury to a zoöphyte. There is often some degree of sensibility apparent throughout a clump, even when of considerable size, but in an hour, their tentacles will again have expanded; and such as were torn by the fracture will be in the process of complete restoration to the former size and powers. The fragments broken off, dropping in a favorable place, would become the germ of another coral plant, its base cementing by means of new coral secretions to the rock on which it might rest. Each animal might live and grow if separated from the rest, and would ultimately produce a mature zoöphyte.

Ordinary corals have a hardness a little above that of common limestone or marble. It is a common error, of old date, to suppose that coral when first removed from the water is soft, and afterwards hardens on exposure. It is composed

of from ninety-five to ninety-eight per cent. of carbonate of lime, the remaining small fraction being mainly water and organic matters. The sea-water, and ordinary food of the polyps, are evidently the sources from which the ingredients of coral are obtained. The powers of life may make from the elements present whatever results the functions of the animal require.

NULLIPORES. The more important species of the *Vegetable Kingdom* that affords stony material for coral reefs are called Nullipores. They are true Algæ, or sea-weeds, although so completely stony and solid that nothing in their aspect is plant-like. They form incrustations over surfaces of dead corals or coral rock. Besides the more stony kinds, there are delicate species, often jointed, called *corallines*, which secrete only a little lime in their tissues, and have a more plant-like look. Even these grow so abundantly on some coasts that, when broken up, and accumulated along the shore, they make thick calcareous deposits. Agassiz has described such beds as having considerable extent in the Florida seas.

Reef-forming corals exist only in, or near the torrid zones, where the temperature of the water is from sixty-eight to eighty-five degrees Fahr., and there is little reason to doubt that *twenty fathoms* may be received as the ordinary limit in depth of reef corals in the tropics. Coral reefs are, it is true, formed to a much greater thickness than this. In fact, Mr. Darwin has estimated the thickness of the reefs of some of the Pacific islands to be at least *two thousand feet*. Now as reef corals do not grow below twenty fathoms, there is no other way in which this two thousand feet of reef could have been formed except by a gradual subsiding of the land upon which it stands. The fact that subsidence has actually taken place during the formation of many reefs is put beyond a doubt.

Coral reefs and islands are beds of solid limestone, made of corals, with the help of shells; sometimes, by undisturbed

growth, with only additions of fine materials to fill up the intervals; sometimes by the grinding of the corals and shells to fragments, as fine as sand, and even mud, by the action of the waves, which are afterwards formed into the very finest and most compact unfossiliferous limestones. Some of the most compact and flint-like limestones are, in fact, nothing but consolidated mud, or fine sand of coral origin.

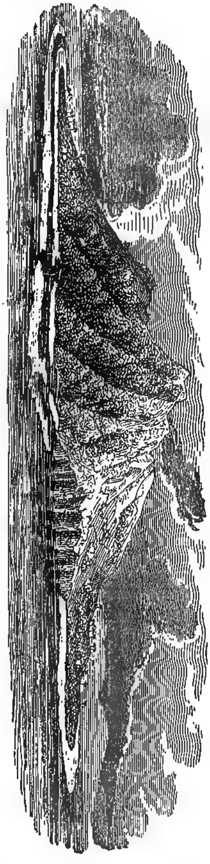


FIG. XXII. HIGH ISLAND, WITH BARRIER AND FRINGING REEFS.

They are structures of the same kind, under somewhat different conditions. They are made in the same seas, and by the same means; in fact, *Coral Islands* are reefs that stand isolated in the ocean, while the term *coral reef*, although used for reefs of coral in general, is more especially applied to those which occur along the shores of high islands and continents. They usually skirt the shores of tropical islands, and are wholly submerged at high tide, but at the ebb they commonly present to view a broad, flat surface of rock, just above the water level, and cause a line of heavy breakers, which are very dangerous to approach, except under the most favorable circumstances for the navigator.

Some idea of the features of a tropical island thus bordered, may be derived from Fig. XXII. The reef to the right is observed to fringe the shore, making a simple broad platform, as an extension of the land. To the left there is the same coral platform at the surface, but it is divided by a chan-

nel into an inner and an outer reef, a *fringing* and a *barrier* reef, as these two parts are called. At a single place the sea is faced by a cliff; and here, owing to the boldness of the shores, and depth of waters, the reef is wanting. The barrier reef at one point has a passage through it, which is an opening into a harbor. While some islands have only narrow fringing reefs, others are almost or quite surrounded by the distant barrier, which stands off like an artificial mole, ten or fifteen miles from the land, and sometimes encloses not only one, but several high islands.

The seas outside of the lines of coral reefs are often unfathomable within a short distance of the line of breakers.

CORAL-HEADS are isolated islets of reef-rock, which are found where the tides are not heavy, or where there is partial protection from them. They are shaped somewhat like a giant mushroom, having a narrow trunk or column below, supporting a broad shelf of reef above. One of these, seen near Turk's Island, is described as follows: Its trunk, which was about thirty feet in height, was only fifteen feet in diameter, and it supported a great tabular mass one hundred feet in diameter, whose top was bare at low tide. In many places these tops are joined together, leaving arches between them; and a case is reported of a whale having gone through one of these passages, after having been struck with a harpoon, taking the rope with him to which it was attached. Sometimes vessels striking heavily on small coral-heads break them off, and escape without injury, at other times they stick fast on them, to the amazement of the captain, who finds deep water all around him, the vessel being perched on the coral-head, like a weathercock on the top of a tower.

STRUCTURE OF CORAL ISLANDS.

Coral Islands, or *Atolls*, as they are called, resemble the reefs just described, except that a lake or lagoon is encircled instead of a mountainous island. A narrow rim of coral reef, generally but a few hundred yards wide, stretches

around the enclosed waters. In some parts, the reef is so low that the waves are still dashing over it into the lagoon; in others it is verdant with the rich foliage of the tropics. The coral-made land, when highest, is seldom more than ten or twelve feet above high tide.

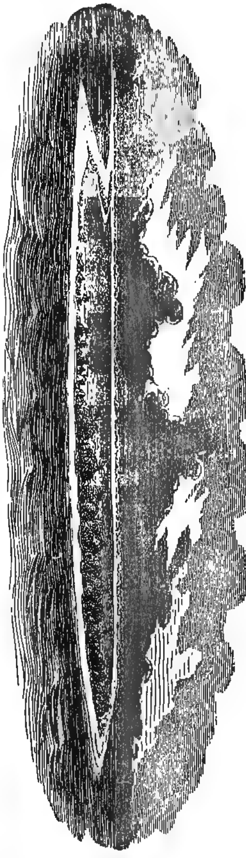


FIG. XXIII. CORAL ISLAND, OR ATOLL.

When first seen from the deck of a vessel, only a series of dark points is descried just above the horizon. Shortly after the points enlarge into the plumed tops of cocoanut trees, and a line of green, interrupted at intervals, is traced along the water's surface. Approaching still nearer, the lake and its belt of verdure are spread out before the eye, and a scene of more interest can scarcely be imagined. The surf, beating loud and heavy along the margin of the reef, presents a strange contrast to the prospect beyond. The belt of verdure, though sometimes continuous, is usually broken into islets, separated by varying intervals of bare reef, and through these intervals a ship channel often exists, opening into the lagoon. Fig. XXIII. shows a completed Atoll, in which no ship channel or interval exists.

The lagoons of the smaller islands are usually very shallow; and in some merely a dry bed remains, indicating the former existence of water. When direct communication with the sea is cut off, these shallow waters sometimes become very salt from evaporation, and others become fresh from

frequent rains, and in either case coral life is destroyed. The completed Atoll is a quiet scene of grove and lake, and admirably set off by the contrasting ocean. The coral-made land is firm, and the groves and plants take firm hold of the soil, and grow in all their natural strength and beauty. Palm trees grow with great beauty and luxuriance. The inhabitants are half-naked savages, ignorant of the existence of other peoples of the world.

Coral reefs and islands are formed by fields of growing coral spread over submarine lands, such as the shores of continents and islands, where the depth is not greater than their habits require. Accumulations of fragments and sand from the coral zoöphytes growing over the reef-grounds, and of shells and other relics of organic life, are constantly making; and thus a bed of coral débris is formed, which is, by the action of the waves, carried into the interstices of the coral bed, and finally compacted in the solid limestone. This making of coral sand and mud is just like that of any other kind of sand and mud. They are made by the self-triturating sands of the reefs, acted upon by the force of the moving waters. It takes place on all shores exposed to the waves, coral or not coral, and in every case the gentler the prevailing movement of the water, the finer the material on the shore. The progress of coral formation is like its commencement. The production of débris will necessarily continue to go on: a part will be swept by the waves across the patch of reef into the lagoon or channel beyond, while other portions will fill up the spaces among the corals along its margin, or be thrown beyond the margin, and lodge on its surface. The layer of coral which has reached the surface of the water and become dead, has still a border of growing coral on its shelving sides, and is thus undergoing extension at its margin, both through the increase in the corals, and the débris dropped among them. But besides the small fragments, larger masses will be thrown on the reefs by the more violent waves, and commence to raise them above the sea.

The *clinker fields* of coral by this means produced, constitute the first step in the formation of dry land. Afterwards, by further contributions of the coarse and fine coral material, the islets are completed, and raised as far out of the water as the waves can reach — that is, about ten feet with a tide of three feet, and sixteen with a tide of six feet. The ocean is thus the architect, while the coral polyps afford the material for the structure; and when all is ready, it sows the land with seed brought from distant shores, covering it with verdure, and preparing it for the habitation of man.

RATE OF GROWTH. It is evident that a reef increases its height or extent with extreme slowness, the rate of increase in thickness, where all is most favorable, not exceeding, perhaps, a sixteenth of an inch a year, or five feet in a thousand years. At this rate some of the Pacific Ocean reefs must have been growing nearly four hundred thousand years. And yet such limestones probably form at a more rapid rate than those made of shells, because the animals are to a larger extent calcareous, and make larger secretions.

We have mentioned the fact that the great thickness of coral formations can only be accounted for by the gradual subsidence of the land upon which they grow. Coral islands are really monuments erected over departed lands; and through the evidence from such records, it is discovered that the Pacific has its deep-water mountain chains, or lines of volcanic summits, not merely hundreds, but thousands of miles in length. Some of these ranges of high islands are proved by such records to have an under-water prolongation, longer than that above water: the Hawaiian Islands, for example, which have an extreme length of only five hundred and thirty miles, stretch on westward, under water, as the coral registers show, to a distance of *two thousand* miles.

This coral island subsidence is an example of one of the great secular movements of the earth's crust. The axis of the subsiding area has a length of more than six thousand miles, and the breadth is over twenty-five hundred miles,

thus equalling the width of the North American continent. A movement of such extent, involving so large a part of the earth's crust, could not have been a local change of level, but one in which the whole sphere was concerned as a unit; for all parts, whether participating or not, must have in some way been in sympathy with it.

This subsidence was in progress, in all probability, during the Glacial era. It was a downward movement for the Tropical Pacific, and perhaps for the warmer latitudes of all the oceanic areas, while the more northern lands, or at least those of North America, were making their *upward* movement, preparatory to, or during that age of ice.

This *subsidence* amounted to several, perhaps full ten thousand feet, and this is about equal to the amount of *elevation* which the Rocky Mountains, Andes, Alps, and Himalayas have each experienced since the close of the Cretaceous era, or the early Tertiary; and perhaps it does not exceed the upward bulging in the Glacial era of part of northern North America.

Had there been no growing coral, the whole of this subsidence would have passed without a record. From the actual size of the coral reefs and islands, we know that the whole amount of high land lost to the Pacific by it greatly exceeds fifty thousand square miles; and some of the islands afford evidence of a *subsidence still in progress*, while the greater portion of them are now rising; some showing coral rock six hundred feet above the sea.

8. Unconscious Action of the Brain.

A Lecture, by DR W. B. CARPENTER, F. R. S., *Author of "The Microscope and its Revelations," &c., delivered in Manchester, England, December* 1, 1871.

I AM going this evening to carry you into a field of inquiry, which I venture to think I have had some share in myself promoting, into what goes on in the depths of our own minds. And I think I shall be able to show you that some practical results of great value in our own mental culture, as training and as discipline, may be deduced from this inquiry. I shall begin with an anecdote that was related to me after a lecture which I gave upon this subject about five years ago, at the Royal Institution, in London. As I was coming out from the lecture-room, a gentleman stopped me, and said, "A circumstance occurred recently in the north of England, which I think will interest you, from its affording an exact illustration of the doctrine which you have been setting forth to-night." The illustration was so apposite, and leads us so directly into the very heart of the inquiry, that I shall make it, as it were, the text for the commencement of this evening's lecture. The manager of a bank in a certain large town in Yorkshire could not find a key which gave access to all the safes and desks in the bank. This key was a duplicate key, and ought to have been found in a place accessible only to himself and to the assistant manager. The assistant manager was absent on a holiday in Wales, and the manager's first impression was that the key had probably been taken away by his assistant in mistake. He wrote to him, and learned, to his own great surprise and distress, that he had not the key, and knew nothing of it. Of course, the idea that the key, which gave access to every valuable in the bank was in the hands of any wrong person, having been taken with a felonious intention, was to him most distressing.

He made search everywhere, thought of every place in which the key might possibly be, and could not find it. The assistant manager was recalled, both he and every person in the bank were questioned, but no one could give any idea of where the key could be. Of course, although no robbery had taken place up to this point, there was the apprehension that a robbery might be committed after the storm, so to speak, had blown over, when a better opportunity would be afforded by the absence of the same degree of watchfulness. A first class detective was then brought down from London, and this man had every opportunity given him of making inquiries; every person in the bank was brought up before him; he applied all those means of investigation which a very able man of this class know how to employ; and at last he came to the manager, and said, "I am perfectly satisfied that no one in the bank knows anything about this lost key. You may rest assured that you have put it somewhere yourself, and you have been worrying yourself so much about it that you have forgotten where you put it away. As long as you worry yourself in this manner, you will not remember it; but go to bed to-night with the assurance that it will be all right; get a good night's sleep; and in the morning I think it is very likely you will remember where you have put the key." This turned out exactly as it was predicted. The key was found the next morning in some extraordinarily secure place, which the manager had not previously thought of, but in which he then felt sure he must have put it himself.

Now, then, ladies and gentlemen, this you may say is merely a remarkable case of that which we all of us are continually experiencing; and so I say it is. Who is there among you who have not had occasion some time or other to try to recall something to his mind which he has not been able to bring to it? He has seen some one in the street, for instance, whose face he recognizes, and says, "I ought to know that person;" and thinks who it can be, going over

his whole list of friends and acquaintances in his mind, without being able to recall who it is; and yet, some hours afterwards, or it may be the next day, it flashes into his mind who this unknown person is. Or you may want to remember some particular and recent event; or it may be, as I have heard classical scholars say, to recall the source of a classical quotation. They "cudgel their brains," to use a common expression, and are unsuccessful; they give their minds to something entirely different; and some hours afterwards, when their thoughts are far away from the subject on which they had been concentrating them with the idea of recovering this lost clew, the thing flashes into the mind. Now, this is so common an occurrence, that we pass it by without taking particular note of it; and yet I believe that the inquiry into the real nature of this occurrence may lead us to understand something of the inner mechanism of our own minds which we shall find to be very useful to us.

There is another point, however, arising out of the story which I have just told you, upon which again I would fix your attention: Why and how did the detective arrive at this assurance from the result of his inquiries? It was a matter of judgment based upon long practice and experience, which had given him that kind of insight into the characters, dispositions, and nature of the persons who were brought before him, which only those who have that faculty as an original gift, or have acquired it by very long experience, can possess with anything like that degree of assurance which he was able to entertain. I believe that this particular power of the detective is, so to speak, an exaltation in a particular direction of what we call "common sense." We are continually bringing to the test of this common sense a great number of matters which we cannot decide by reason; a number of matters as to which, if we were to begin to argue, there may be so much to be said on both sides, that we may be unable to come to a conclusion. And yet, with regard to a great many of these subjects — some of which I shall have

to discuss in my next lecture — we consider that common sense gives us a much better result than any elaborate discussion. Now I will give you an illustration of this, which you will all readily comprehend. Why do we believe in an external world? Why do I believe that I have at present before me many hundreds of intelligent auditors, looking up and listening to every word that I say? Why do you believe that you are hearing me lecture? You will say at once that your common sense tells you. I see you; you see and hear me; and I know that I am addressing you. But if once this subject is logically discussed, if once we go into it on the basis of a pure reasoning process, it is found really impossible to construct such a proof as shall satisfy every logician. As far as my knowledge extends, every logician is able to pick a hole in every other logician's proof. Now here we have then a case obvious to you all, in which common sense decides for us without any doubt or hesitation at all. And I venture to use an expression upon this point which has been quoted with approval by one of the best logicians and metaphysicians of our time, Archbishop Manning, who cited the words that I have used, and entirely concurred in them, namely, that "in regard to the existence of the external world the common-sense decision of mankind is practically worth more than all the arguments of all the logicians who have discussed the basis of our belief in it." And so, again, with regard to another point which more nearly touches our subject to-night — the fact that we have a Will which dominates over our actions; that we are not merely the slaves of automatic impulse which some philosophers would make us — "the decision of mankind (as Archbishop Manning, applying my words, has most truly said) derived from consciousness of the existence of our living self or personality, whereby we think, will, or act, is practically worth more than all the arguments of all the logicians who have discussed the basis of our belief in it."

Now, then, my two points are these: What is the nature

of this process which evolves, as it were, this result unconsciously to ourselves, when we have been either asleep, as in the case of the banker, or, as in the other familiar case I have cited, when we have been giving our minds to some other train of thought in the interval? What is it that brings up spontaneously to our consciousness a fact which we endeavored to recall with all the force of our will, and yet could not succeed?

And then, again, What is the nature of this common sense, to which we defer so implicitly and immediately in all the ordinary judgments of our lives?

Now, in order that we may have a really scientific conception of the doctrine I would present to you, I must take you into an inquiry with regard to some of the simpler functions of our bodies, from which we shall rise to the simpler actions of our minds. You all know that the brain, using the term in its general sense, is the organ of our mind. That every one will admit. We shall not go into any of the disputed questions as to the relations of mind and matter; for the fact is, that these are now coming to take quite a new aspect, from physical philosophers dwelling so much more upon force than they do upon matter, and on the relations of mind and force, which every one is coming to recognize. Thus, when we speak of nerve-force and mind as having a most intimate relation, no one is found to dispute it; whereas, when we talk about brain and mind having this intimate relation, and mind being the function of the brain, there are a great many who will rise up against us, and charge us with materialism, and atheism, and all the other deadly sins of that kind. I merely speak of the relation of the brain to the mind, as the instrument through which the mind operates and expresses itself. We all know that it is in virtue of the impressions carried to the brain through the nerves proceeding from the different sensory organs in various parts of the body, that we become conscious of what is taking place around us. And, again, that it is through the nerves proceeding from the

brain that we are able to execute those movements which the will prompts and dictates, or which arise from the play of the emotions. But I have first to speak of a set of lower centres, those which the will can, to a certain extent, control, but which are not in such immediate relation to it as is the brain. You all know that there passes down our backbone a cord which is commonly called the "spinal marrow." Now, this spinal marrow gives off a pair of nerves at every division of the backbone; and these nerves are double in function — one set of fibres conveying impressions from the surface to the spinal cord, the other motor impulses from the spinal cord to the muscles. Now it used to be considered that this spinal cord (I use the term spinal cord, which is the same as spinal marrow, because it is just as intelligible and more correct) was a mere bundle of nerves proceeding from the brain; but we have long known that that is not the case, that the spinal cord is really a nervous centre in itself, and that if there were no brain at all the spinal cord would still do a great deal. For example, there have been infants born without a brain, yet these infants have breathed, have cried, have sucked, and this in virtue of the separate existence and the independent action of this spinal cord. Let us analyze one or two of these actions. We will take the act of sucking as the best example, because experiments have been made upon young puppies, by taking out the brain, and then trying whether they would suck; and it was found that putting between the lips the finger moistened with milk or with sugar and water, produced a distinct act of suction, just as when an infant is nursed. Now how is this? It is what we call a "reflex action." I shall have a good deal to say of reflex action higher up in the nervous system, and, therefore, I must explain precisely what we mean by that term. It is just this. There is a certain part of the spinal cord, at the top of the neck, which is what we call a ganglion; that is, a centre of nervous power: in fact the whole of the spinal cord is a series of such ganglia; but this ganglion at the top of

the neck is the one which is the centre of the actions which are concerned in the act of sucking. Now this act of sucking is rather a complicated one, it involves the action of a great many muscles put into conjoint and harmonious contraction. We will say, then, that here is a nervous centre. [Dr. Carpenter made a sketch upon the blackboard.] These are nerves coming to it, branches from the lips; and these another set, going to the muscles concerned in the movement of sucking from it. Thus, by the conveyance to the ganglionic centre of the impression made on the lips, a complicated action is excited, requiring the combination of a number of separate muscular movements. We will take another example — the act of coughing. You feel a tickling in your throat, and you feel an impulse to cough which you cannot resist; and this may take place not only when you are awake and feel the impulse, but when you are asleep, and do not feel it. You will often find persons coughing violently in sleep, without waking or showing any sign of consciousness. Here, again, the stimulus, as we call it, produced by some irritation in the throat, gives rise to a change in the nerves going towards the ganglionic centre, which produces the excitement of an action in that centre that issues the mandate, so to speak, through the motor nerves to the muscles concerned in coughing, which actions have to be united in a very remarkable manner, which I cannot stop to analyze; but the whole action of coughing has for its effect the driving out a violent blast of air, which tends to expel the offending substance. Thus when anything "goes the wrong way," as we term it — a crumb of bread, or a drop of water finding its way into the windpipe, then this sudden and violent blast of air tends to expel it.

Now these are examples of what we call "reflex action;" and this is the character of most of the movements that are immediately concerned with the maintenance of the vital functions. I might analyze other cases. The act of breathing is a purely reflex action, and goes on when we are

perfectly unconscious of exerting any effort, and when our attention is entirely given up to some act or thought; and even when asleep the act of breathing goes on with perfect regularity, and if it were to stop, of course the stoppage would have a fatal effect upon our lives. But most of these reflex actions are to a certain degree placed under the control of our will. If it were not for this controlling power of will, I could not be addressing you at this moment. I am able so to regulate my breath as to make it subservient to the act of speech; but that is the case only to a certain point. I could not go on through a long sentence without taking my breath. I am obliged to renew the breath frequently, in order to be able to sustain the circulation and other functions of life. But still I have that degree of control over the act of respiration, that I can regulate this drawing in and expulsion of the breath for the purpose of speech. This may give you an idea of the way in which mental operations may be independent of the will, and yet be under its direction. To this we shall presently come.

Now those reflex actions of the spinal cord, which are immediately and essentially necessary to the maintenance of our lives, take place from the commencement without any training, without any education; they are what we call "instinctive actions;" the tendency to them is part of our nature; it is born with us. But, on the other hand, there are a great many actions which we learn, to which we are trained in the process of bodily education, so to speak, and which, when we have learned them, come to be performed as frequently, regularly, methodically, and unconsciously as those of which I have spoken. This is the case particularly with the act of walking. You all know with how much difficulty a child is trained to that action. It has to be learned by a long and painful experience, for the child usually gets a good many tumbles in the course of that part of its education; but when once acquired it is as natural as the act of breathing, only it is more directly under the control of the will;

yet so completely automatic does it become, that we frequently execute a long series of these movements without any consciousness whatever. You start in the morning, for instance, to go from your home to your place of employment; your mind is occupied by a train of thought, something has happened which has interested you, or you are walking with a friend and in earnest conversation with him; and your legs carry you on without any consciousness on your part that you are moving them. You stop at a certain point, the point at which you are accustomed to stop, and very often you will be surprised to find that you are there. While your mind has been intent upon something else, either the train of thought which you were following out in your own mind, or upon what your friend has been saying, your legs move on of themselves, just as your heart beats, or as your muscles of breathing continue to act. But this is an acquired habit; this is what we call a "secondarily automatic" action. Now that phrase is not very difficult when you understand it. We speak then of the actions being "automatic," when we mean that they take place of themselves, without any direction on our own parts; such as the act of sucking in the infant, the acts of respiration and swallowing, and others which are entirely involuntary, and are of this purely reflex character. Now those are "primarily automatic," that is originally automatic; we are born with a tendency to execute them; but the actions of the class I am now speaking of are executed by the same portion of the nervous system — the spinal cord — and are "secondarily automatic," that is to say, we have to learn them, but when once learned, they come very much into the condition of the others, only we have some power of will over them. We start ourselves in the morning by an act of the will; we are determined to go to a particular place; and it may be that we are conscious of these movements over the whole of our walk; but, on the other hand, we may be utterly unconscious of them, and continue to be so until either we have arrived at our journey's end or begin

to feel fatigued. Now when we begin to feel fatigued, we are obliged to maintain the action by an effort of the will; we are no longer unconscious, and we are obliged to struggle against the feeling of fatigue, to exert our muscles in order to continue the action.

Now, having set before you this reflex action of the spinal cord, you will ask me, perhaps, what is the exciting cause of this succession of actions in walking. I believe it is the contact of the ground with the foot at each movement. We put down the foot, that suggests as it were to the spinal cord the next movement of the leg in advance, and that foot comes down in its turn, and so we follow with this regular rhythmical succession of movements.

We next pass to a set of centres somewhat higher, those which form the summit, as it were, of this spinal cord, which are really imbedded in the brain, but which do not form a part of that higher organ, which is in fact the organ of the higher part of our mental nature, yet which are commonly included in that which we designate the brain. In fact, the anatomist who only studies the human brain is very liable to be misled in regard to the character of these different parts, by the fact that the higher part — that which we call the cerebrum — is so immensely developed in man, in proportion to the rest of the animal creation, that it envelopes, as it were, the portion of which I am about to speak, concealing it and reducing it apparently to the condition of a very subordinate part; and yet that subordinate part is, as I shall show you, the foundation or basis of the higher portion — the cerebrum itself. The brain of a fish consists of a very little else than a series of these ganglia, these little knots — the word "ganglion" means "knot," and the ganglia in many instances, when separated, are little knots, as it were, upon the nerves. The brain of a fish consists of a series of these ganglia, one pair belonging to each principal organ of sense. Thus we have in front the ganglia of smell, then the ganglia of sight, the ganglia of hearing, and the ganglia of general

sensation. These constitute almost entirely the brain of the fish. There is scarcely anything in the brain of the fish which answers to the cerebrum or higher part of the brain of man. I will give you an idea of the relative development of these parts. [Dr. Carpenter made other sketches on the blackboard to represent these ganglia of sense in man and the lower animals.] Now, the cerebrum in most fishes is a mere little film, overlaying the sensory tract, but in the higher fish we have it larger; in the reptiles we have it larger still; and in birds we have it still larger; in the lower mammalia it is larger still; and then as we ascend to man this part becomes so large in proportion that my board will not take it in. This cerebrum, this great mass of the brain, at the bottom of which these ganglia of sense are buried, as it were, so overlies and conceals them that their essential functions for a long time remained unknown. Now, in the cerebrum, the position of the active portion, what we call the ganglionic matter, that which gives activity and power to these nervous centres, is peculiar. In all ganglia this "gray" matter, as it is called, is distinct from the white matter. In ordinary ganglia, this gray matter lies in the interior as a sort of little kernel; but in the cerebrum it is spread out over the surface, and forms a film or layer. If any of you have the curiosity to see what it is like, you have only to get a sheep's brain and examine it, and you will see this film of a reddish substance covering the surface of the cerebrum. In the higher animals and in the man this film is deeply folded upon itself, with the effect of giving it a very much more extended surface, and in this manner the blood vessels come into relation with it; and it is by the changes which take place between this nervous matter and the blood that all our nervous power is produced. You might liken it roughly to the galvanic battery by which the electic telegraph acts, the white or fibrous portion of the brain and nerves being like the conducting wires of the telegraph. Just as the fibres of the nerves establish a communication between the organs of sensation

and the ganglionic centres, and again between the ganglionic centres and the muscles, so do the white fibres which form a great part of the brain, establish a communication between the gray matter of the convoluted or folded surface of the cerebrum and the sensory ganglia at its base. Now I believe that this sensory tract which lies at the base of the skull is the real *sensorium*, that is, the centre of sensation; that the brain at large, the cerebrum, the great mass of which I have been speaking, is not in itself the centre of sensation; that, in fact, the changes which take place in this gray matter only rise to our consciousness, — only call forth our conscious mental activity, — when the effect of those changes is transmitted downwards to this sensorium. Now this sensorium receives the nerves from the organs of sense. Here, for instance, is the nerve from the organ of smell, here from the eye, and here from the body generally (the nerves of touch), and here the nerves of hearing — every one of these has its own peculiar function. Now these sensory ganglia have in like manner reflex actions. I will give you a very curious illustration of one of these reflex actions. You all know the start we make at a loud sound or a flash of light; the stimulus conveyed through our eyes from the optic nerve to the central ganglion, causing it to send through the motor nerves a mandate that calls our muscles into action. Now this may act sometimes in a very important manner for our protection, or for the protection of some of our delicate organs. A very eminent chemist a few years ago was making an experiment upon some extremely explosive compound which he had discovered. He had a small quantity of this compound in a bottle, and was holding it up to the light, looking at it intently; and whether it was a shake of the bottle or the warmth of his hand, I do not know, but it exploded in his hand, the bottle was shivered into a million of minute fragments, and those fragments were driven in every direction. His first impression was that they had penetrated his eyes, but to his intense relief he found, presently, that they

had only penetrated the outside of his eyelids. You may conceive how infinitesimally short the interval was between the explosion of the bottle and the particles reaching his eyes; and yet in that interval the impression had been made upon his sight, the mandate of the reflex action, so to speak, had gone forth, the muscles of his eyelids had been called into action, and he had closed his eyelids before the particles reached them, and in this manner his eyes were saved. You see what a wonderful proof this is of the way in which the automatic action of our nervous apparatus enters into the sustenance of our lives, and the protection of our most important organs from injury.

Now I have to speak of the way in which this automatic action of the sensory nerves and of the motor nerves which answer to them, grows up as it were in ourselves. We will take this illustration. Certain things are originally instinctive, the tendency to them is born with us; but in a very large number of things we educate ourselves, or we are educated. Take, for instance, the guidance of the class of movements I was speaking of just now — our movements of locomotion. We find that when we set off in the morning with the intention of going to our place of employment, not only do our legs move without our consciousness, if we are attending to something entirely different, but we guide ourselves in our walk through the streets; we do not run up against anybody we meet; we do not strike ourselves against the lamp-posts; and we take the appropriate turns which are habitual to us. It has often happened to myself, and I dare say it has happened to every one of you, that you have intended to go somewhere else — that when you started you intended instead of going in the direct line to which you were daily accustomed, to go a little out of your way to perform some little commission; but you have got into a train of thought and forgotten yourself, and you find that you are half way along your accustomed track before you become aware of it. Now there you see is the same automatic action of these sensory ganglia — we see, we hear — for in-

stance, we hear the rumbling of the carriages, and we avoid them without thinking of it; our muscles act in respondence to these sights and sounds, and yet all this is done without our intentional direction — they do it for us. Here again, then, we have the "secondarily automatic" action of this power, that of a higher nervous apparatus which has grown, so to speak, to the mode in which it is habitually exercised. Now that is a most important consideration. It has grown to the mode in which it is habitually exercised; and that principle, as we shall see, we shall carry into the higher class of mental operations.

But there is one particular kind of this action of the sensory nerves to which I would direct your attention, because it leads us to another very important principle. You are all of you, I suppose, acquainted with the action of the stereoscope; though you may not all know that its peculiar action, the perception of solidity it conveys to us, depends upon the combination of two dissimilar pictures — the two dissimilar pictures which we should receive by our two eyes of an object if it were actually placed before us. If I hold up this jug, for instance, before my eyes, straight before the centre of my face, my two eyes receive pictures which are really dissimilar. If I made two drawings of the jug, first as I see it with one eye, and then with the other, I should represent this object differently. For instance, as seen with the right eye I see no space between the handle and the body of the jug; as I see it with the left eye I see a space there. If I were to make two drawings of that jug as I now see it with my two eyes, and put them into a stereoscope, they would bring out, even if only in outline, the conception of the solid figure of that jug in a way that no single drawing could do. Now that conception is the result of our early-acquired habit of combining with that which we *see* that which we *feel*. That habit is acquired during the first twelve or eighteen months of infancy. When your little children are lying in their cradles and are handling a solid object, a block of wood,

or a simple toy, and are holding it at a distance from their eyes, bringing it to their mouth and then carrying it to arm's length, they are going through a most important part of their education; that part of their education which consists in the harmonization of the mental impressions derived from sight and those derived from the touch; and it is by that harmonization that we get that conception of solidity or projection, which, when we have once acquired it, we receive from the combination of these two dissimilar pictures alone, or even, in the case of objects familiar to us, without two dissimilar pictures at all — the sight of the object suggesting to us the conception of its solidity and of its projection.

Now this is a thing so familiar to you, that few of you have probably ever thought of reasoning it out; and in fact it has only been by the occurrence of cases in which persons have grown to adult age without having acquired this power, from having been born blind, and having only received sight by a surgical operation at a comparatively late period, when they could describe things as they saw them; I say it is only by such cases that we have come to know how completely dissimilar and separate these two classes of impressions really are, and how important is this process of early infantile education of which I have spoken. A case occurred a few years ago in London where a friend of my own performed an operation upon a young woman who had been born blind, and though an attempt had been made in early years to cure her, that attempt had failed. She was able just to distinguish large objects, the general shadow as it were of large objects without any distinct perception of form, and to distinguish light from darkness. She could work well with her needle by the touch, and could use her scissors and bodkin and other implements by the training of her hand, so to speak, alone. Well, my friend happened to see her, and he examined her eyes, and told her that he thought he could get her sight restored; at any rate, it was worth a trial. The operation succeeded; and being a man of intelligence and quite

aware of the interest of such a case, he carefully studied and observed it; and he completely confirmed all that had been previously laid down by the experience of similar cases. There was one little incident which will give you an idea of the education which is required for what you would suppose is a thing perfectly simple and obvious. She could not distinguish by sight the things that she was perfectly familiar with by the touch, at least, when they were first presented to her eyes. She could not recognize even a pair of scissors. Now you would have supposed that a pair of scissors, of all things in the world, having been continually used by her, and their form having become perfectly familiar to her hands, would have been most readily recognized by her sight; and yet she did not know what they were; she had not an idea until she was told, and then she laughed, as she said, at her own stupidity. No stupidity at all; she had never learned it, and it was one of those things which she could not know without learning. One of the earliest cases of this kind was related by the celebrated Cheselden, a surgeon of the early part of last century. Cheselden relates how a youth just in this condition had been accustomed to play with a cat and a dog; but for some time after he attained his sight he never could tell which was which, and used to be continually making mistakes. One day being rather ashamed of himself for having called the cat the dog, he took up the cat in his arms and looked at her very attentively for some time, stroking her all the while; and in this way he associated the impression derived from the sight of the cat with the impression derived from the touch, and made himself master (so to speak) of the whole idea of the animal. He then put the cat down, saying, "Now puss, I shall know you another time."

Now the reason why I have specially directed your attention to this is because it leads to one of the most important principles that I desire to expound to you this evening— what I call in mental physiology the doctrine of *resultants*. All of you who have studied mechanics know very well

what a "resultant" means. You know that when a body is acted on by two forces at the same time, one force carrying it in this direction, and another force in that direction, we want to know in what direction it will go, and how far it will go. To arrive at this we simply complete what is called the parallelogram of forces. In fact it is just as if a body was acted on at two different times, by a force driving it in one direction, and then by a force driving it in the other direction. [Dr. Carpenter illustrated this point by the aid of the blackboard.] We draw two lines parallel to this, and we draw a diagonal — that diagonal is what is called the resultant; that is, it expresses the direction, and it expresses the distance — the length of the motion which that body will go when acted upon by these two forces. Now I use this term as a very convenient one to express this — that when we have once got the conception that is derived from the harmonization of these two distinct sets of impressions on our nerves of sense, we do not fall back on the original impressions, but we fall back on the resultant, so to speak. The thing has been done for us; it is settled for us; we have got the resultant; and the combination giving that resultant is that which governs the impression made upon our minds by all similar and future operations of the same kind. We do not need to go over the processes of judgment by which the two sets of impressions are combined in every individual case; but we fall back, as it were, upon the resultant. Now what is the case in the harmonization of the two classes of impressions of sight and touch, I believe to be true of the far more complicated operations of the mind of which the higher portion of the brain, the cerebrum, is the instrument. Now this cerebrum we regard as furnishing, so to speak, the mechanism of our thoughts. I do not say that the cerebrum is that which does the whole work of thinking, but it furnishes the mechanism of our thought. It is not the steam engine that does the work; the steam engine is the mere mechanism; the work is done, as my friend Professor Roscoe would

tell you, by the heat supplied; and if we go back to the source of that heat, we find it originally in the heat and light of the sun that made the trees grow by which the coal was produced, in which the heat of the sun is stored up, as it were, and which we are now using, I am afraid, in rather wasteful profusion. The steam engine furnishes the mechanism; the work is done by the force. Now in the same manner, the brain serves as the mechanism of our thought; and it is only in that sense that I speak of the work of the brain. But there can be no question at all that it works of itself, as it were, — that it has an automatic power, just in the same manner as the sensory centres and the spinal cord have automatic power of their own. And that a very large part of our mental activity consists of this automatic action of the brain, according to the mode in which we have trained it to action, I think there can be no doubt whatever. And the illustration with which I started in this lecture gives you, I believe, a very good example of it. However, there are other examples which are in some respects still better illustrations of the automatic work that is done by the brain, in the state which is sometimes called Second Consciousness, or Somnambulism — to which some persons are peculiarly subject. I heard only a few weeks ago of an extremely remarkable example of a young man who had overworked himself in studying for an examination, and who had two distinct lives, as it were, in each of which his mind worked quite separately and distinct from the other. One of these states, however, — the ordinary one, — is under the control of the will to a much greater extent than the other; while the secondary state is purely, I suppose, automatic. There are a great many instances on record of very curious mental work, so to speak, done in this automatic condition — a state of active dreaming in fact. For instance, Dr. Abercrombie mentions, in his very useful work on the Intellectual Powers, an example of a lawyer who had been excessively perplexed about a very complicated question. An opinion was required from him, but

the question was one of such difficulty that he felt very uncertain how his opinion should be given. The opinion had to be given on a certain day, and he awoke in the morning of that day with a feeling of great distress. He said to his wife, "I had a dream, and the whole thing in that dream has been clear before my mind, and I would give anything to recover that train of thought." His wife said to him, "Go and look on your table." She had seen him get up in the night and go to his table and sit down and write. He went to his table, and found there the very opinion which he had been most earnestly endeavoring to recover, lying in his own handwriting. There was no doubt about it whatever, and this opinion he at once saw was the very thing which he had been anxious to be able to give. A case was put on record of a very similar kind only a few years ago by a gentleman well known in London, the Rev. John De Liefde, a Dutch clergyman. This gentleman mentioned it on the authority of a fellow-student who had been at the college at which he studied in early life. He had been attending a class in mathematics, and the professor said to his class one day, "A question of great difficulty has been referred to me by a banker, a very complicated question of accounts — which they have not themselves been able to bring to a satisfactory issue, and they have asked my assistance. I have been trying, and I cannot resolve it. I have covered whole sheets of paper with calculations, and have not been able to make it out. Will you try?" He gave it as a sort of problem to his class, and said he should be extremely obliged to any one who would bring him the solution by a certain day. This gentleman tried it over and over again; he covered many slates with figures, but could not succeed in resolving it. He was a little put on his mettle, and very much desired to attain the solution; but he went to bed on the night before the solution, if attained, was to be given in, without having succeeded. In the morning, when he went to his desk, he found the whole problem worked out in his own hand.

He was perfectly satisfied that it was his own hand; and this was a very curious part of it — that the result was correctly obtained by a process very much shorter than any he had tried. He had covered three or four sheets of paper in his attempts, and this was all worked out upon one page, and correctly worked, as the result proved. He inquired of his "hospita," as she was called — I believe our English equivalent is bed-maker, the woman who attended to his rooms — and she said she was certain that no one had entered his room during the night. It was perfectly clear that this had been worked out by himself.

Now there are many cases of this kind, in which the mind has obviously worked more clearly and more successfully in this automatic condition, when left entirely to itself, than when we have been cudgelling our brains, so to speak, to get the solution. I have paid a good deal of attention to this subject, in this way: I have taken every opportunity that occurred to me of asking inventors and artists — creators in various departments of art — musicians, poets, and painters, what their experience has been in regard to difficulties which they have felt, and which they have after a time overcome. And the experience has been almost always the same, that they have set the result which they have wished to obtain strongly before their minds, just as we do when we try to recollect something we have forgotten; they think of everything that can lead to it; but if they do not succeed, they put it by for a time, and give their minds to something else, and endeavor to obtain as complete a repose or refreshment of the mind upon some other occupation as they can; and they find that either after sleep, or after some period of recreation by a variety of employment, just what they want comes into their heads. A very curious example of this was mentioned to me a few years ago by Mr. Wenham, a gentleman who has devoted a great deal of time and attention to the improvement of the microscope, and who is the inventor of that form of binocular microscope (by which we look

with two eyes and obtain a stereoscopic picture), which is in general use in this country. The original binocular microscope was made upon a plan which would suggest itself to any optician. I shall not attempt to describe it to you, but it involved the use of three prisms, giving a number of reflections; and every one of these reflections were attended with a certain loss of light and a certain liability to error. And besides that, the instrument could only be used as a binocular microscope. Now, Mr. Wenham thought it might be possible to construct an instrument which would work with only one prism, and that this prism could be withdrawn, and then we could use the microscope for purposes to which the binocular microscope could not be applied. He thought of this a great deal, but he could not think of the form of prism which would do what was required. He was going into business as an engineer, and he put his microscopic studies aside for more than a fortnight, attending only to his other work, and thinking nothing of his microscope. One evening, after his day's work was done, and while he was reading a stupid novel, as he assured me, and was thinking nothing whatever of his microscope, the form of the prism that should do this work flashed into his mind. He fetched his mathematical instruments, drew a diagram of it, worked out the angles which would be required, and the next morning he made his prism, and found it answered perfectly well; and upon that invention nearly all the binocular microscopes made in this country have since been constructed.

I could tell you a number of anecdotes of this kind, which would show you how very important is this automatic working of our minds — this work which goes on without any more control or direction of the will, than when we are walking and engaged in a train of thought which makes us unconscious of the movements of our legs. And I believe that in all these instances — such as those I have named, and a long series of others — the result is owing to the mind being left to itself without the disturbance of any emotion. It was

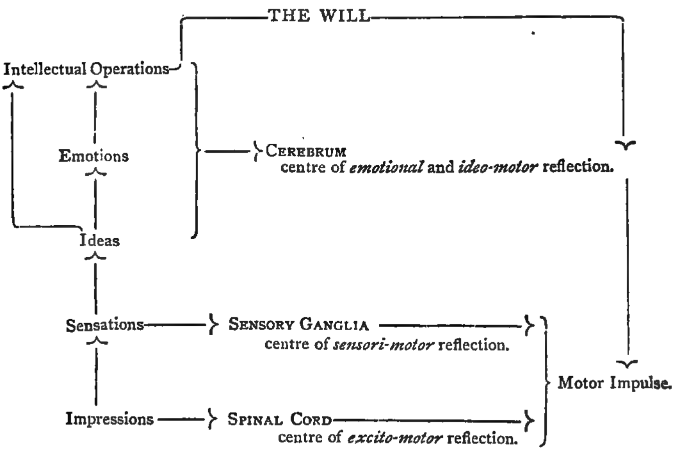
the worry which the bank manager had been going through, that really prevented the mind from working with the steadiness and evenness that produced the result. So in the case of the lawyer; so in the case of the mathematician, — they were all worrying themselves, and did not let their minds have fair play. You have heard, I dare say, and those of you who are horsemen may have had experience, that it is a very good thing sometimes, if you lose your way on horseback, to drop the reins on the horse's back, and let him find his way home. You have been guiding the horse into one path and into another, and following this and that path, and you find that it does not lead you in the right direction; just let the horse go by himself, and he will find his way better than you can. In the same manner, I believe, that our minds, under the circumstances I have mentioned, really do the work better than our wills can direct. The will gives the impulse in the first instance, just as when you start on your walk; and not only this, but the will keeps before the mind all the thoughts which it can immediately lay hold of, or which association suggests, that bear upon the subject. But then these thoughts do not conduct immediately to an issue, they require to work themselves out; and I believe that they work themselves out very often a great deal better by being left to themselves. But then we must recollect that such results as these are only produced in the mind which has been trained and disciplined; and that training and discipline are the result of the control of the will over the mental processes, just as in the early part of the lecture I spoke to you of the act of speech as made possible by the control which the will has over the muscles of breathing. We cannot stop these movements — we must breathe — but we can regulate them, and modify them, and intensify them, or we can check them for a moment, in accordance with the necessities of speech. Well, so it is, I think, with regard to the action of our will upon our mental processes. I believe that this control, this discipline of the will, should be learned very early; and I

will give to the mothers amongst you, especially, one hint in regard to a most valuable mode of training it even in early childhood. I learned this, I may say, from a nurse whom I was fortunate enough to have, and whose training of my own sons in early childhood I regard as one of the most valuable parts of their education. She was a sensible country girl, who could not have told her reasons, but whose instincts guided her in the right direction. I studied her mode of dealing with the children, and learned from that the principle. Now the principle is this: A child falls down and hurts itself. (I take the most common of nursery incidents. You know that Sir Robert Peel used to say that there were three ways of looking at this question; and there are three modes of dealing with this commonest of nursery incidents.) One nurse will scold the child for crying. The child feels the injustice of this; it feels the hurt, and it feels the injustice of being scolded. I believe that is the most pernicious of all the modes of dealing with it. Another coddles the child, takes it up, and rubs its head, and says, "O naughty chair, for hurting my dear child!" I remember learning that one of the royal children fell against a table in the queen's presence, and the nurse said, "O naughty table," when the queen very sensibly said, "I will not have that expression used; it was not the table that was naughty; it was the child's fault that he fell against the table." I believe that this method is extremely injurious; the result of it being that it fixes the child's attention upon its hurt, and causes it to attain that habit of self-consciousness which is in after life found to have most pernicious effects. Now, what does the sensible and judicious nurse do? She distracts the child's attention, holding it up to the window to look at the pretty horses, or gets it a toy to look at. This excites the child's attention, and the child forgets its hurt, and in a few moments is itself again, unless the hurt has been severe. When I speak of coddling, I mean about a trifling hurt, such as is forgotten in a few moments; a severe injury is a different matter. But I believe

that the coddling is only next in its evil results (when followed out as a system) to the evil effects of the system of scolding; the distraction of the attention is the object to be aimed at. Well, after a time, the child comes to be able to distract its own attention. It feels that it can withdraw its own mind from the sense of its pain, and can give its mind to some other object, to a picture-book, or to some toy, or whatever the child feels an interest in; and that is the great secret of self-government in later life. We should not say, "I won't think of this"—some temptation, for instance; *that* simply fixes the attention upon the very thought that we wish to escape from; but the true method is—"I will think of something else;" *that*, I believe, is the great secret of self-government, the knowledge of which is laid in the earliest periods of nursery life.

Now just direct your attention to this diagram, as a sort of summary of the whole:—

[DIAGRAM.]



You see I put at the top the Will. The will dominates everything else. I do not pretend to explain it, but I simply

say, as Archbishop Manning said, in applying my own language to this case, that our common sense teaches us that we have a will, that we have the power of self-government and self-direction, and that we have the power of regulating and dominating all these lower tendencies to a certain extent, not to an unlimited extent. We cannot prevent those thoughts and feelings rising in our minds that we know to be undesirable; but we can escape from them, we can repress them; but, as I said, the effort to escape from them is much more effectual than the effort to repress them, excepting when they arise with great power, and then we have immediately, as it were, to crush them out; but when they tend to return over and over again, the real mode of subduing them is to determine to give our attention to something else. It is by this exercise of the will, therefore, in training and disciplining the mind, that it acquires that method by which it will work of itself. The mathematician could never have worked out that difficult problem, nor the lawyer have given his opinion, nor the artist have developed those conceptions of beauty which he endeavors to shape either in music, or poetry, or painting, but for the training and disciplining which his mind has undergone. The most wonderfully creative of all musicians, Mozart, whose music flowed from him with a spontaneousness that no musician, I think, has ever equalled — Mozart went through, in early life, a most elaborate course of study, imposed upon him, in the first instance, by his father, and afterwards maintained by himself. When his contemporaries remarked how easily his compositions flowed from him, he replied, "I gained the power by nothing but hard work." Mozart had a most extraordinary combination of this intuitive musical power, with the knowledge derived from patient and careful study, that probably any man ever attained. Now in the same manner we have persons of extraordinary natural gifts, and see these gifts frequently running to waste, as it were, because they have not received this culture and discipline. And it is this discipline which gives

us the power of performing, unconsciously to ourselves, these elaborate mental operations; because I hold that a very large part of our mental life thus goes on, not only automatically, but even below the sphere of our consciousness. And you may easily understand this, if you refer to the diagram which I drew just now on the blackboard. You saw that the cerebrum, the part that does the work, what is called the convoluted surface of the brain, lies just immediately under the skull cap; that it is connected with the sensorium at the base of the brain by a series of fibres which are merely, I believe, conducting fibres. Now I think that it is just as possible that the cerebrum should work by itself when the sensorium is otherwise engaged or in a state of unconsciousness, as that impressions should be made on the eye of which we are unconscious. A person may be sleeping profoundly, and you may go and raise the lid and bring a candle near, and you will see the pupil contract; and yet that individual shall see nothing, for he is in a state of perfect unconsciousness. His eye sees it, so to speak, but his mind does not; and you know that his eye sees it by the contraction of the pupil, which is a reflex action; but his mind does not see it, because the sensorium is in a state of inaction. In the same manner during sleep the cerebrum may be awake and working, and yet the sensorium shall be asleep, and we may know nothing of what the cerebrum is doing except by the results. And it is in this manner, I believe, that, having been once set going, and the cerebrum having been shaped, so to speak, in accordance with our ordinary processes of mental activity, having grown to the kind of work we are accustomed to set it to execute, the cerebrum can go on and do its work for itself. The work of invention, I am certain, is so mainly produced, from concurrent testimony I have received from a great number of inventors, or what the old English called "makers"— what the Greeks called poets, because the word poet means a maker. Every inventor must have a certain amount of imagination, which may be exercised in mechanical contrivance

or in the creations of art; these are *inventions* — they are made, they are produced, we don't know how; the conception comes into the mind we cannot tell whence; but these inventions are the result of the original capacity for that particular kind of work, trained and disciplined by the culture we have gone through. It is not given to every one of us to be an inventor. We may love art thoroughly, and yet we may never be able to evolve it for ourselves. So in regard to humor. For instance, there are some men who throw out flashes of wit and humor in their conversation, who cannot help it — it flows from them spontaneously. There are other men who enjoy this amazingly, whose nature it is to relish such expressions keenly, but who cannot make them themselves. The power of invention is something quite distinct from the intellectual capacity or the emotional capacity for enjoying and appreciating; but although we many not have these powers of invention, we can all train and discipline our minds to utilize that which we do possess to its utmost extent. And here is the conclusion to which I would lead you in regard to common sense. We fall back upon this, that common sense is, so to speak, the *general resultant of the whole previous action of our minds*. We submit to common sense any questions — such questions as I shall have to bring before you in my next lecture; and the judgment of that .common sense is the judgment elaborated as it were by the whole of our mental life. It is just according as our mental life has been good, and true, and pure, that the value of this acquired and this higher common sense is reached. We may in proportion I believe to our honesty in the search for truth — in proportion as we discard all selfish considerations and look merely at this grand image of truth, so to speak, set before us, with the purpose of steadily pursuing our way towards it — in proportion as we discard all low and sensual feelings in our love of beauty, and especially in proportion to the earnestness of the desire by which our minds are pervaded always to keep the right before us in all our judgments — so

I believe will our minds be cleared in their perception of what are merely prudential considerations. It has on several occasions occurred to me to form a decision as to some important change either in my own life, or in the life of members of my family, which involved a great many of what we are accustomed to call *pros* and *cons* — that is, there was a great deal to be said on both sides. I heard the expression once used by a naturalist, with regard to difficulties in classification: "It is very easy to deal with the white and the black; but the difficulty is to deal with the gray." And so it is in life. It is perfectly easy to deal with the white and the black, — there are things which are clearly right, and things which are clearly wrong; there are things which are clearly prudent, and things which are clearly imprudent; but a great many cases arise in which even right and wrong may seem balanced, or the motives may be so balanced that it is difficult to say what is right; and again there are cases in which it is difficult to say what is prudent; and I believe in these cases where we are not hurried and pressed for a decision, the best plan is to do exactly that which I spoke of in the earlier part of the lecture — to set before us as much as possible everything that is to be said on both sides. Let us consider this well; let us go to our friends; let us ask what they think about it. They will suggest considerations which may not occur to ourselves. It has happened to me within the last three or four months to have to make a very important decision of this kind for myself; and I took this method: I heard everything that was to be said on both sides, I considered it well, and then I determined to put it aside as completely as possible for a month, or longer, if time should be given, and then to take it up again, and simply just to see how my mind gravitated — how the balance then turned. And I assure you that I believe that in those who have disciplined their minds in the manner I have mentioned, that act of "unconscious cerebration," for so I call it, this unconscious operation of the brain in balancing for itself all these

considerations, in putting all in order, so to speak, in working out the result — I believe that that process is far more likely to lead us to good and true results than any continual discussion and argumentation, in which one thing is pressed with undue force, and then that leads us to bring up something on the other side, so that we are just driven into antagonism, so to speak, by the undue pressure of the force which we think is being exerted. I believe that to hear everything that is to be said, and then not to ruminate upon it too long, not to be continually thinking about it, but to put it aside entirely from our minds as far as we possibly can, is the very best mode of arriving at a correct conclusion. And this conclusion will be the *resultant* of the whole previous training and discipline of our minds. If that training and discipline has all been in the direction of the true and the good, I believe that we are more likely to obtain a valuable result from such a process than from any conscious discussion of it in our minds, anything like continually bringing it up and thinking of it, and going over the whole subject again in our thoughts. The unconscious settling down, as it were, of all these respective motives, will, I think, incline the mind ultimately to that which is the just and true decision.

There is just one other point I could mention in connection with this subject: the manner in which the *conscious* direction and discipline of the mind will tend to remove those *unconscious* prejudices that we all have more or less from education, from the circumstances in which we were brought up; and from which it is excessively difficult for us to free ourselves entirely. I have known a great many instances in public and in private life, in which the most right-minded men have every now and then shown the trammelling, as it were, of their early education and early associations, and were not able to think clearly upon the subject in consequence of this. These early prejudices and associations cling around us, and influence the thoughts and feelings of the honestest men in the world unconsciously; and it is some-

times surprising to those who do not know the force of these early associations, to see how differently matters which are to them perfectly plain and obvious are viewed by men whom we feel we must respect and esteem. Now I believe that it is the earnest habit of looking at a subject from first principles, and, as I have said over and over again, looking honestly and steadily at the true and the right, which gives the mind that direction that ultimately overcomes the force of these early prejudices and these early associations, and brings us into that condition which approaches the nearest of anything that I think we have the opportunity of witnessing in our earthly life, to that *direct insight*, which many of us believe will be the condition of our minds in that future state in which they are released from all the trammels of our corporeal existence.

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9. Epidemic Delusions.

A Lecture by DR. CARPENTER, F. R. S., *delivered in Manchester, December* 8, 1871.

OUR subject to-night links itself in such a very decided manner to the subject in which we were engaged last week, and the illustrations which I shall give you are so satisfactorily explained on the scientific principle which I endeavored then to expound to you, that I would spend a very few minutes in just going over some of the points to which I then particularly directed your attention. My object was to show you that between our mental operations and our will there is something of that kind of relation which exists between a well-trained horse and his rider; that the will, — if rightly exercised in early infancy in directing and controlling the mental operations; in directing the attention to the objects to which the intellect should be applied; in controlling and repressing emotional disturbance; restraining the feelings when unduly excited, and putting a check upon the passions — that the will in that respect has the same kind of influence over the mind, or ought to have, as the rider has upon his horse; that the powers and activities of the mind are to a very great degree independent of the will; that the mind will go on of itself without any more than just the starting of the will, in the same manner as a horse will go on in the direction that it has been accustomed to go with merely the smallest impulse given by the voice, or the hand, or the heel of the rider, and every now and then a very slight check (if it is a well-trained horse) or guidance from the bridle or from a touch of the spur, and will follow exactly the course that the rider desires, but by its own independent power. And, again, I showed you that as there are occasions on which a horse is best left to itself, so there are occa-

sions when the mind is best left to itself, without the direction and control of the will; in fact in which the operations of the mind are really disturbed by being continually checked and guided and pulled up by the action of the will, the result being really less satisfactory than when the mind, previously trained and disciplined in that particular course of activity, is left to itself. I gave you some curious illustrations of this from occurrences which have taken place in dreaming, or in that form of dreaming which we call somnambulism: where a legal opinion had been given, or a mathematical problem had been resolved, in the state of sleep-waking; that is to say the mind being very much in the condition of that of the dreamer, its action being altogether automatic, going on of itself without any direction or control from the will, but the bodily activity obeying the direction of the mind. And then I went on to show you that this activity very often takes place, and works out most important results, even without our being conscious of any operations going on; and that some of these results are the best and most valuable to us in bringing at last to our consciousness ideas which we have been vainly searching for, — as in the case where we have endeavored to remember something that we have not at first been able to retrace, and which has flashed into our minds in a few hours, or it may be a day or two afterwards; or, again, when we have been directing our minds to the solution of some problem which we have put aside in a sort of despair, and yet in the course of a little time that solution has presented itself while our minds have either been entirely inactive, as in sleep, or have been directed into some entirely different channel of action.

Now, like a well-trained horse which will go on of itself with the smallest possible guidance, yet still under the complete domination of the rider, and will even find its way home when the rider cannot direct it thither, we find that the human mind sometimes does that which even a well-trained horse will do — that it runs away from the guidance of its

directing will. Something startles the horse, something gives it alarm, and it makes a sudden bound, and then, perhaps, sets off at a gallop, and the rider cannot pull it up. This alarm often spreads contagiously, as it were, from one horse to another; as we lately saw in the "stampede" at Aldershot. Or, again, a horse, even if well trained, when he gets a new rider, sometimes, as we say, "tries it on," to see whether the horse or the rider is really the master. I have heard many horsemen say that that is a very familiar experience. When you first go out with a new horse, it may be to a certain degree restive; but if the horse finds that you keep a tight hand upon him, and that his master knows well how to keep him under control, a little struggling may have to be gone through, and the horse from that time becomes perfectly docile and obedient. But if, on the other hand, the horse finds that *he* is the master, even for a short time, no end of trouble is given afterwards to the rider in acquiring that power which he desires to possess. Now that is just the case with our minds; we may follow out the parallel very closely indeed. We find that if our minds once acquire habits — habits of thought, habits of feeling — which are independent of the will, which the will has not kept under adequate regulation, these habits get the better of us; and then we find that it is very difficult indeed to recover that power of self-direction which we have been aiming at, and which the well-trained and well-disciplined mind will make its highest object. So, again, we find that there are states in which, from some defect in the physical condition of the body, or it may be from some great shock which has affected the mind and weakened for a time the power of the will, very slight impulses — just like the slight things that will make a horse shy — will disturb us unduly; and we feel that our emotions are excited in a way that we cannot account for, and we wonder why such a little thing should worry and vex us in the way that it does. Even the best of us know, within our own personal experience, that when we

are excessively fatigued in body, or overstrained in mind, our power of self-control is very much weakened; so that particular ideas will take possession of us, and for a time will guide our whole course of thought, in a manner which our sober judgment makes us feel to be very undesirable. What, for instance, is more common than for a person to take offence at something that has been said or done by his most intimate friend, or by some member of his family, merely because he has been jaded or overtasked, and has not the power of bringing to the fair judgment of his common sense the question whether that offence was really intended, or whether it was a thing he ought not to take any notice of? He broods over this notion, and allows it to influence his judgment; and if he does not in a day or two rouse himself and master his feelings by throwing it off, it may give rise to a permanent estrangement. We are all of us conscious of states of mind of that kind.

But there are states of mind which lead to very much more serious disorder, arising from the neglect of that primary discipline and culture on which I have laid so much stress. We find that ignorance, and that want of the habit of self-control which very commonly accompanies it, predispose very greatly indeed to the violent excitement of the feelings, and to the possession of the mind by ideas which we regard as essentially absurd, and under these states of excitement of feeling, and the tendency of these dominant ideas to acquire possession of the intellect, the strangest aberrations take place, not only in individuals but in communities; and it is of such that I have especially to speak to-night. We know perfectly well, in our individual experience, that these states tend to produce insanity if they are indulged in, and if the individual does not make an earnest effort to free himself from their influence. But, looking back at the history of the earlier ages, and carrying that survey down to the present time, we have experience in all ages of great masses of people being seized upon by these dominant ideas, accompanied

with the excitement of some passion or strong impulse which leads to the most absurd results; and it is of these Epidemic Delusions I have to now speak. The word "epidemic" simply means something that falls upon, as it were, the great mass of the people — a delusion which affects the popular mind. And I believe that I can best introduce the subject to you by showing you how, in certain merely physical conditions, mere bodily states, there is a tendency to the propagation, by what is commonly called imitation, of very strange actions of the nervous system. I suppose there is no one of you who does not know what an hysteric fit means; a kind of fit to which young women are especially subject, but which affects the male sex also. One reason why young women are particularly subject to it is, that in the female the feelings are more easily excited, while the male generally has a less mobile nervous system, his feelings being less easily moved, while he is more influenced by the intellect. These hysteric fits are generally brought on by something that strongly affects the feelings. Now, it often happens that a case of this sort presents itself in a school or nunnery, sometimes in a factory where a number of young women are collected together; one being seized with a fit, others will go off in a fit of a very similar kind. There was an instance a good many years ago in a factory in a country town in Lancashire, in which a young girl was attacked with a violent convulsive fit, brought on by alarm, consequent upon one of her companions, a factory operative, putting a mouse down inside her dress. The girl had a particular antipathy to mice, and the sudden shock threw her into a violent fit. Some of the other girls who were near very soon passed off into a similar fit; and then there got to be a notion that these fits were produced by some emanations from a bale of cotton; and the consequence was that they spread, till scores of the young women were attacked day after day with these violent fits. The medical man who was called in saw at once what the state of things was; he assured them in the first place that

this was all nonsense about the cotton; and he brought a remedy, in the second place, which was a very appropriate one under the circumstances — namely, an electrical machine; and he gave them some good violent shocks, which would do them no harm, assuring them that this would cure them. And cure them it did. There was not another attack afterwards. I remember very well that when I was a student at Bristol, there was a ward in the hospital to which it was usual to send young servant girls; for it was thought undesirable that these girls should be placed in the ward with women of a much lower class, especially the lower class of Irish women who inhabited one quarter of Bristol, as I believe there is an Irish quarter in Manchester. These girls were mostly respectable, well-conducted girls, and it was thought better that they should be kept together. Now the result of this was that if an hysteric fit took any one of them, the others would follow suit; and I remember perfectly well, when I happened to be resident pupil, having to go and scold these girls well, threatening them with some very severe infliction. I forget what was threatened; perhaps it would be a shower-bath, for any one who went off into one of these fits. Now here the cure is effected by a stronger emotion, the emotion of the dread of — we will not call it punishment — but of a curative measure; and this emotion overcame the tendency to what we commonly call imitation. It is the suggestion produced by the sight of one, that brings on the fit in another, where there is the predisposition to it. Now I believe that in all these cases there is something wrong in the general health or in the nervous system, or the suggestion would not produce such results. Take the common teething fits of children. We there see an exciting cause in the cutting of the teeth; the pressure of the tooth against the gum being the immediate cause of the production of convulsive action. But it will not do so in a healthy child. I feel sure that in every case where there is a teething fit, of whatever kind, there is always some unhealthy condition of the

nervous system — sometimes from bad food, more commonly from bad air. I have known many instances in which children had fits with every tooth that they cut, yet when sent into the country they had no recurrence of the fit. There must have been some predisposition, some unhealthy condition of the nervous system, to favor the exciting cause, which, acting upon this predisposition, brings out such very unpleasant results.

There are plenty of stories of this kind that I might relate to you. For instance, in nunneries it is not at all uncommon, from the secluded life, and the attention being fixed upon one subject, one particular set of ideas and feelings — the want of a healthy vent, so to speak, for the mental activity — that some particular odd propensity has developed itself. For instance, in one nunnery abroad, many years ago, one of the youngest nuns began to mew like a cat; and all the others, after a time, did the same. In another nunnery one began to bite, and the others were all affected with the propensity to bite. In one of these instances the mania was spreading like wildfire through Germany, extending from one nunnery to another, and they were obliged to resort to some such severe measures as I have mentioned to drive it out. It was set down in some instances to demoniacal possession, but the devil was very easily exorcised by some pretty strong threat on the part of the medical man. The celebrated physician, Boerhaave, was called in to a case of that kind in an orphan asylum in Holland, and I think his remedy was a red-hot iron. He heated the poker in the fire, and said that the next girl who fell into one of these fits should be burned in the arm; this was quite sufficient to stop it. In Scotland at one time there was a great tendency to breaking out into fits of this kind in the churches. This was particularly the case in Shetland; and a very wise minister there told them that the thing could not be permitted, and that the next person who gave way in this manner — as he was quite sure they could control themselves if they pleased — should be

taken out and ducked in a pond near. There was no necessity at all to put his threat into execution. Here, you see, the stronger motive is substituted for the weaker one, and the stronger motive is sufficient to induce the individual to put a check upon herself. I have said that it usually happens with the female sex, though sometimes it occurs with young men who have more or less of the same constitutional tendency. What is necessary is to induce a stronger motive, which will call forth the power of self-control which has been previously abandoned.

Now this tendency which here shows itself in convulsive movements of the body, will also show itself in what we may call convulsive action of the mind; that is, in the excitement of violent feelings and even passions, leading to the most extraordinary manifestations of different kinds. The early Christians, you know, practised self-mortification to a very great degree, and considered that these penances were so much scored up to the credit side of their account in heaven, — that, in fact, they were earning a title to future salvation by self-mortification. Among other means of self-mortification, they scourged themselves. That was practised by individuals. But in the middle ages this disposition to self-mortification would attack whole communities, especially under the dominant idea that the world was coming to an end. In the middle of the 13th century, about 1250, there was this prevalent idea that the world was coming to an end, and whole communities gave themselves up to this self-mortification by whipping themselves. These flagellants went about in bands with banners, and even music, carrying scourges; and then, at a given signal, every one would strip off the upper garment (men, women, and children joined these bands), and proceed to flog themselves very severely indeed, or to flog each other. This subsided for a time, but it broke out again during and immediately after that terrible plague which is known as the "black death," which devastated Europe in the reign of Edward III., about the year

1340. This black death seems to have been the Eastern Plague in a very severe form, which we have not known in this country since the great plague of London in Charles II.'s time, and one or two smaller outbreaks since, but which has now entirely left us. The severity of this plague in Europe was so great that upon a very moderate calculation one in four of the entire population were carried off by it, and in some instances it is said that nine tenths of the people died of it. You may imagine, therefore, what a terrible infliction it was. And you would have supposed that it would have called forth the better feelings of men and women generally; but it did not. One of the worst features, morally, of that terrible affliction was the lamentable suspension of all natural feelings which it seemed to induce. When any member of a family was attacked by this plague, every one seemed to desert him, or desert her; the sick were left to die alone, or merely under the charge of any persons who thought that they would be paid for rendering this service; and the funerals were carried on merely by these paid hirelings in a manner most repulsive to the feelings: and yet the very people who so deserted their relatives would join the bands of flagellants, who paraded about from place to place, and even from country to country, — mortifying their flesh in this manner for the purpose of saving their own souls, and, as they said, also making expiation for the great sins which had brought down this terrible visitation. This system of flagellation never gained the same head in this country that it did on the Continent. A band of about one hundred came to London about the middle of the reign of Edward III., in the year 1350. They came in the usual style, with banners and even instruments of music, and they paraded the streets of London. At a given signal every one lay down and uncovered the shoulders, excepting the last person, who then flogged every one till he got to the front, where he lay down; and the person last in the rear stood up, and in his turn flogged every one in front of him. Then he went to the front and lay

down; and so it went on until the whole number had thus been flogged, each by every one of his fellows. This discipline, however, did not approve itself to the good citizens of London, and it is recorded that the band of flagellants returned without having made any converts. Whether the skins of the London citizens were too tender, or whether their good sense prevailed over this religious enthusiasm, we are not informed; but at any rate the flagellants went back very much as they came, and the system never took root in this country; yet for many years it was carried on elsewhere. One very curious instance is given of the manner in which it fastened on the mind — that mothers actually scourged their new-born infants before they were baptized, believing that in so doing they were making an offering acceptable to God. Now all this appears to us perfectly absurd. We can scarcely imagine the state of mind that should make any sober, rational persons suppose that this could be an offering acceptable to Almighty God; but it was in accordance with the religious ideas of the time; and for a good while even the church sanctioned and encouraged it, until at last various moral irregularities grew up, of a kind that made the Pope think it a very undesirable thing, and it was then put down by ecclesiastical authority; yet it was still practised in secret for some time longer, so that it is said that even until the beginning of the last century there were small bands of flagellants in Italy who used to meet for this self-mortification.

That was one form in which a dominant idea took possession of the mind and led to actions which might be called voluntary, for they were done under this impression, that such self-mortification was an acceptable offering. But there were other cases in which the action of the body seemed to be in a very great degree involuntary, just about as involuntary as an hysteric fit, and yet in which it was performed under a very distinct idea; such was what was called the "Dancing Mania," which followed upon this great plague. This dancing mania seemed in the first instance to seize upon persons who had a

tendency to that complaint which we now know as St. Vitus's dance — St. Vitus was in fact the patron saint of these dancers. St. Vitus's dance, or chorea, in the moderate form in which we now know it, is simply this, that there is a tendency to jerking movements of the body, these movements sometimes going on independently of all voluntary action, and sometimes accompanying any attempt at voluntary movement; so that the body of a person may be entirely at rest until he desires to execute some ordinary movement, such as lifting his hand to his head to feed himself, or getting up to walk; then, when the impulse is given to execute a voluntary movement, instead of the muscles obeying the will, the movement is complicated as (it were) with violent jerking actions, which show that there is quite an independent activity. The fact is that stammering is a sort of chorea. We give the name of chorea to this kind of disturbance of the nervous system, and the action of stammering is a limited chorea — chorea limited to the muscles concerned in speech, when the person cannot regulate the muscles so as to bring out the words desired; the very strongest effort of his will cannot make the muscles obey him, but there is a jerking irregular action every time he attempts to pronounce particular syllables. And the discipline that the stammerer has to undergo in order to cure or alleviate his complaint is just the kind of discipline I have spoken of so frequently — the fixing the attention on the object to be gained, and regularly exercising the nerves and muscles in proceeding from that which they *can* do to that which they find a difficulty in doing. That is an illustration of the simpler form of this want of definite control over the muscular apparatus, connected with a certain mental excitement; because every one knows that a stammerer is very much affected by the condition of his feelings at the time. If, for example, he is at all excited, or if he apprehends that he shall stammer, that is enough to produce it. I have known persons who never stammered in ordinary conversation, yet when in company with stammerers they could

scarcely avoid giving way to it; and even when the subject of stammering was talked about, when the idea was conveyed to their minds, they would begin to hesitate and stutter, unless they put a very strong control upon themselves. It is just in this way, then, only in the most exaggerated form, that these persons were afflicted with what was called the dancing mania. They would allow themselves to be possessed with the idea that they *must* dance; and this dancing went on, bands going from town to town, and taking in any who would join them. Instances are recorded in which they would go on for twenty-four or thirty-six hours, continually jumping and dancing and exerting themselves in the most violent manner, taking no food all this time, until at last they dropped on the ground almost lifeless; and in fact several persons, it is said, did die from pure exhaustion, and this just because they were possessed with the idea that they *must* dance. They were drawn in, as it were, by the contagion of example; and when once they had given way to it, they did not know when to stop. This was kept up by music and by the encouragement and excitement of the crowd around; and it spread amongst classes of persons who (it might be supposed) would have had more power of self-restraint, and would not have joined such unseemly exhibitions. The extraordinary capacity, as it were, for enduring physical pain, was one of the most curious parts of this condition. They would frequently ask to be struck violently; would sometimes lie down and beg persons to come and thump and beat them with great force. They seemed to enjoy this. — In another case that I might mention this was shown still more. The case was of a similar type, but was connected more distinctly with the religious idea, and it occurred much more recently. The case was that known in medical history as the Convulsionnaires of St. Mêdard. There was a cemetery in Paris in which a great saint had been interred, and some young women visiting his tomb had been thrown into a convulsive attack which propagated itself extensively; and these con-

vulsionnaires spreading the contagion, as it were, into different classes of French society, one being seized after another till the number became very great in all grades. Here, again, one of the most curious things was the delight they seemed to take in what would induce in other persons the most violent physical suffering. There was an originized band of attendants, who went about with clubs, and violently beat them. This was called the *grand secours*, which was administered to those who were subject to these convulsive attacks. You would suppose that these violent blows with the clubs would do great mischief to the bodies of these people; but they only seemed to allay their suffering.

This, then, is another instance of the mode in which this tendency to strange actions under the dominance of a particular idea will spread through a community. Here you have the direct operation of the perverted mind upon the body. But there are a great many cases in which the perversion shows itself more in the mental state alone, leading to strange aberrations of Mind, and ultimately to very sad results in the condition of society where these things have spread, but not leading to anything like these convulsive paroxysms. I particularly allude now to the epidemic belief in Witchcraft, which, more or less, formerly prevailed constantly amongst the mass of the population, but every now and then broke out with great vehemence. This belief in witchcraft comes down to us from very ancient periods; and at the present time it is entertained by the lowest and most ignorant of the population in all parts of the world. We have abundant instances of it still, I am sorry to say, in our own community. We have poor ignorant servant girls allowing themselves to be — if I may use such a word — " humbugged " by some designing old woman, who persuades them that she can predict the husbands they are to have, or tell where some article that they have lost is to be found, and who extracts money from them merely as a means of obtaining a living in this irregular way, and I believe at the bottom rather enjoying the cheat.

Every now and then we hear of some brutal young farmer who has pretty nearly beaten to death a poor old woman, whom he suspected of causing a murrain amongst his cattle. This is what we know to exist amongst the least cultivated of the savage nations at the present time, and always to have existed. But we hope that the progress of rationalism in our own community, will, in time, put an end to this, as it has in the middle and upper ranks of society during the last century or century and a half. It is not very long since almost every one believed in the possession of these occult powers by men and women, but especially by old women. This belief has prevailed generally in countries which have been overridden by a gloomy fanaticism in religious matters. I speak simply as a matter of history. There is no question at all that this prevailed where the Romish Church was most intolerant, especially in countries where the Inquisition was dominant, and its powers were exerted in such a manner as to repress free thought and the free exercise of feeling; and, again, where strong Calvinism has exercised an influence of exactly the same kind — as in Scotland, a century and a half ago, and in New England, where there was the same kind of religious fanaticism. It is in these communities that belief in witchcraft has been most rife, has extended itself most generally, and has taken possession of the public mind most strongly; and the most terrible results have happened. Now I will only cite one particular instance, that of New England, in the early part of the last century and the end of the century before. Not very long after the settlement of New England, there was a terrible outbreak of this belief in witchcraft. It began in a family, the children of which were out of health; and certain persons whom they disliked were accused of having bewitched them. Against these persons a great deal of evidence that we should now consider most absurd was brought forward, and they were actually executed: and some of them under torture, or under moral torture, — for it was not merely physical torture that

was applied; in many cases it was the distress and moral torture of being so accused, the dread, even if found not guilty, of being considered outcasts all their lives, or of being a burden to their friends, — made confessions which any sober person would have considered perfectly ridiculous; but under the dominant idea of the reality of this witchcraft, no one interfered to point out how utterly repugnant to common sense these confessions were, as well as the testimony that was brought forward. And this spread to such a degree in New England, one person being accused after another, that at last, even those who considered themselves God's chosen people began to feel, "our turn may come next;" they then began to think better of it, and so put an end to these accusations, even some who were under sentence being allowed to go free; and to the great surprise of those who were entirely convinced of the truth of these accusations, this epidemic subsided, and witchcraft was not heard of for a long time afterwards; so that the belief has never prevailed in New England from that time to the present, excepting amongst the lowest and most ignorant class. In Scotland, these witch persecutions attained to a most fearful extent during the seventeenth century. They were introduced into England very much by James I., who came to England possessed by these ideas, and he communicated them to others, and there were a good many witch persecutions during his reign. After the execution of Charles I., and during the time of the Commonwealth and the Puritans, there were a good many witch persecutions; but I think after that, very little more was heard of them. And yet the belief in witchcraft lingered for a considerable time longer. It is said that even Dr. Johnson was accustomed to remark, that he did not see that there was any proof of the non-existence of witches; that though their existence could not be proved, he was not at all satisfied that they did not exist. John Wesley was a most devout believer in witchcraft, and said on one occasion that if witchcraft was not to be believed, we could not believe in the Bible. So

you see that this belief had a very extraordinary hold over the public mind. It was only the most intelligent class, whose minds had been freed from prejudice by general culture, who were really free from it; and that cultivation happily permeated downwards, as it were; so that now I should hope there are very few amongst our intelligent working class in our great towns — where the general culture is much higher than it is in the agricultural districts — who retain anything more than the lingering superstition which is to be found even in the very highest circles — as, for instance, not liking to be married on Friday, or not liking to sit down thirteen at the dinner-table. These are things which even those who consider themselves the very aristocracy of intellect will sometimes confess to, laughing at it all the time, but saying, "It goes against the grain, and I would rather not do it." These, I believe, are only lingering superstitions that will probably pass away in another half century, and we shall hear nothing more of them; the fact being that the tendency to these delusions is being gradually grown out of.

Now this is the point I would especially dwell upon. To the child-mind nothing is too strange to be believed. The young child knows nothing about the Laws of Nature; it knows no difference between what is conformable to principles, and what, on the other hand, is so strange that an educated man cannot believe it. To the child every new thing that it sees is equally strange; there is none of that power of discrimination that we acquire in the course of our education — the education given to us, and the education that we give ourselves. We gradually, in rising to adult years, grow out of this incapacity to distinguish what is strange from what is normal or ordinary. We gradually come to feel — "Well, I can readily believe that, because it fits in with my general habit of thought; I do not see anything strange in this, although it is a little unusual." But, on the other hand, there are certain things we feel to be too strange and absurd to be believed; and that feeling we come to especially, when we

have endeavored to cultivate our Common Sense in the manner which I described to you in my last lecture. The higher our common sense — that is, the general resultant of the whole character and discipline of our minds — the more valuable is the direct judgment that we form by the use of it. And it is the growth of that common sense, which is the most remarkable feature in the progress of thought during the last century. The discoveries of science; the greater tendency to take rational and sober views of religion; the general habit of referring things to principles; and a number of influences which I cannot stop particularly to describe, have so operated on the public mind, that every generation is raised, I believe, not merely by its own culture, but by the acquired result of the experience of past ages; for I believe that every generation is born, I will not say wiser, but with a greater tendency to wisdom. I feel perfectly satisfied of this, that the child of an educated stock has a much greater power of acquiring knowledge than the child of an uneducated stock; that the child that is the descendant of a race in which high moral ideas have been always kept before the mind, has a much greater tendency to act uprightly than the child that has grown up from a breed that has been living in the gutter for generations past. I do not say that these activities are born with us; but the tendency to them, — that is, the aptitude of mind for the acquirement of knowledge, the facility of learning, the disposition to act upon right principles, — I believe is, to a very great degree, hereditary. Of course we have lamentable examples to the contrary, but I am speaking of the general average. I am old enough now to look back with some capacity of observation for forty years; and I can see in the progress of society a most marked evidence of the higher general intelligence, the greater aptitude for looking at things as they are, and for not allowing strange absurd notions to take possession of the mind; while, again, I can trace, even within the last ten years, in a most remarkable manner, the prevalence of a de-

sire to do things right for the right's sake, and not merely because they are politic. And I am quite sure that there is a gradual progress in this respect, which has a most important influence in checking aberrations of the class of which I have spoken.

Still we see these aberrations; and there is one just now which is exciting a good deal of attention, — that which you have heard of under the name of "Spiritualism." Now I look upon the root of this spiritualism to lie in that which is a very natural, and in some respects, a wholesome disposition of the kind — a desire to connect ourselves in thought with those whom we have loved and who are gone from us. Nothing is more admirable, more beautiful, in our nature than this longing for a continuance of intercourse with those whom we have loved on earth. It has been felt in all nations and at all times, and we all of us experience it in regard to those to whom we have been most especially attached. But this manifestation of it is one which those who experience this feeling in its greatest purity and its greatest intensity feel to be absurd and contrary to common sense — that the spirits of their departed friends should come and rap upon tables, and make chairs dance in the air, and indicate their presence in grotesque methods of this kind. The most curious part of it is that the spirits should obey the directions of the persons with whom they profess to be in communication, — that when they say, "rap once if you mean yes, and rap twice if you mean no," and so on, they should just follow any orders they receive as to the mode in which they will telegraph replies to their questions. It seems to me repugnant to one's common sense; but the higher manifestations of these spiritual agencies seem to me far more repugnant to common sense; and that is when persons profess to be able to set all the laws of nature at defiance; when it is said, for instance, that a human being is lifted bodily up into the air and carried, it may be, two or three miles, and descends through the ceiling of a room. One of the recent statements of this kind,

you know, is that a certain very stout and heavy lady was carried a distance of about two miles from her own house, and dropped plump down upon the table round which eleven persons were sitting; she came down through the ceiling, they could not state how, because they were sitting in the dark; and that darkness has a good deal to do with most of these manifestations. Now, let us analyze them a little. I am speaking now of what I will call the genuine phenomena — those which happen to persons who really are honest in their belief. I exclude altogether, and put aside the cases, of which I have seen numbers, in which there is the most transparent trickery, and in which the only wonder is that any rational persons should allow themselves to be deceived by it.

I have paid a great deal of attention during the last twenty years to this subject, and I can assure you that I have, in many instances, known things most absurd in themselves, and most inconsistent with the facts of the case, as seen by myself and other sober-minded witnesses, believed in by persons of very great ability, and, upon all ordinary subjects, of great discrimination. But I account for it by the previous possession of their minds by this dominant idea — the expectation they have been led to form, either by their own earnest desire for this kind of communication, or by the sort of contagious influence to which some minds are especially subject. I say "the earnest desire," for it is a very curious thing that many of those who are the most devout spiritualists are persons who have been themselves previously rather sceptical upon religious matters; and many have said to me that this communication is really the only basis of their belief in the unseen world. Such being the case, I cannot wonder that they cling to it with very strong and earnest feeling. A lady, not undistinguished in the literary world, assured me several years ago that she had been converted by this spiritualism from a state of absolute unbelief in religion; and she assured me, also, that she regarded medical men and scientific men,

who endeavored to explain these phenomena upon rational principles, and to expose deception, where deception did occur, as the emissaries of Satan, who so feared that the spread of spiritualism would destroy his power upon earth, that he put it into the minds of medical and scientific men to do all that they could to prevent it. Now that, I assure you, is a fact. That was said to me by a lady of considerable literary ability, and I believe it represents, though rather extravagantly, a state of mind which is very prevalent; the great spread of the intense materialism of our age tending to weaken, and in some instances, to destroy, that healthful longing which we all have, I believe, in our innermost nature, for a higher future existence, and which is, to my mind, one of the most important foundations of our belief in it. We live too much in the present; we think too much of the things of the world as regards our material comfort and enjoyment, instead of thinking of them as they bear upon our own higher nature. I believe that this tendency, which I think is especially noticeable in America — or at least it was a few years ago — from all that I was able to learn, had a great deal to do with the spread of this belief in what is called Spiritualism. The spiritualists assert that in America they are numbered by millions; that there are very few people of any kind of intellectual culture who have not either openly or secretly given in their adhesion to it. I believe that is a gross exaggeration; still there can be no doubt from the number of periodicals they maintain, and the advertisements in them of all kinds of strange things that are done, — spirit drawings made, drawings of deceased friends, and spiritual instruction given of various kinds, — that there must be a very extended belief in this notion of communication with the unseen world through these "media."

I can only assure you for myself that having, as I have said, devoted considerable attention to this subject, I have come to the conclusion most decidedly, with, I believe I may say, as little prepossession as most persons, and with every

disposition to seek for truth simply — to allow for our knowledge, or I would rather say for our ignorance, a very large margin of many things that are beyond our philosophy — with every disposition to accept facts when I could once clearly satisfy myself that they were facts — I have had to come to the conclusion that whenever I have been permitted to employ such tests as I should employ in any scientific investigation, there was either intentional deception on the part of interested persons, or else self-deception on the part of persons who were very sober-minded and rational upon all ordinary affairs of life. Of that self-deception I could give you many very curious illustrations, but the limits of our time will prevent my giving you more than one or two. On one occasion I was assured that on the evening before, a long dining table had risen up and stood a foot high in the air, in the house in which I was, and to which I was then admitted for the purpose of seeing some of these manifestations by persons about whose good faith there could be no doubt whatever. I was assured by them, "It was a great pity you were not here last night, for, unfortunately, our principal medium is so exhausted by the efforts she put forth last night, that she cannot repeat it." But I was assured upon the word of three or four who were present, that this table had stood a foot high in the air, and remained suspended for some time, without any hands being near it, or at any rate with nothing supporting it; the hands might be over it. But I came to find from experiments performed in my presence, that they considered it evidence of the table rising into the air, that it pressed upwards against their hands; that they did not rest upon their sense of sight; for I was looking in this instance at the feet of the table, and I saw that the table upon which the hands of the performers were placed, and which was rocking about upon its spreading feet, really never rose into the air at all. It would tilt to one side or to the other side, but one foot was always resting on the ground. And when they declared to me that this table had risen in the air,

I said, "I am very sorry to have to contradict you, but I was looking at the feet of the table all the time, and you were not; and I can assert most positively that one of the feet never left the ground. Will you allow me to ask what is *your* evidence that the table rose into the air?" "Because we felt it pressing upwards against our hands." I assure you that was the answer I received; their conclusion that the table rose in the air being grounded on this, that their hands being placed upon the table, they felt, or they believed, that the table was pressing upwards against their hands, though I saw all the time that one foot of the table had never left the ground. Now that is what we call a "subjective sensation;" one of those sensations which arise in our own minds under the influence of an idea. Take, for instance, the very common case — when we sleep in a strange bed, it may be in an inn that is not very clean, and we begin to be a little suspicious of what other inhabitants there may be in that bed; and then we begin to feel a "creepy, crawly" sensation about us, which that idea will at once suggest. Now those are subjective sensations; those sensations are produced by the mental idea. And so in this case I am perfectly satisfied that a very large number of these spiritual phenomena are simply subjective sensations; that is, that they are the result of expectation on the part of the individual. The sensations are real to them. You know that when a man has suffered amputation of his leg, he will tell you at first that he feels his toes, that he feels his limb; and, perhaps to the end of his life, every now and then he will have this feeling of the limb moving, or of a pain in it; and yet we know perfectly well that that is simply the result of certain changes in the nerve, to which, of course, there is nothing answering in the limb that was removed. These subjective sensations, then, will be felt by the individuals as realities, and will be presented to others as realities, when, really, they are simply the creation of their own minds, that creation arising out of the expectation which they have themselves formed. These

parties believed that the table would rise; and when they felt the pressure against their hands, they fully believed that the table was rising.

Take the case of table-turning, which occurred earlier. I dare say many of you remember that epidemic which preceeded the spiritualism; in fact, the spiritualism, in some degree, arose out of table-turning. My friend, the chairman (Dr. Noble), and I hunted in couples, a good many years ago, with a third friend, the late Sir John Forbes, and we went a great deal into these inquiries; and I very well remember sitting at a table with him, I suppose twenty-five years ago, waiting in solemn expectation for the turning of the table; and the table went round. This was simply the result of one of the party, who was not influenced by the philosophical scepticism that we had on the subject, having a strong belief that the phenomenon would occur; and when he had sat for some time with his hands pressed down upon the table, an involuntary muscular motion, of the kind I mentioned in my last lecture, took place, which sent the table turning. There was nothing to the physiologist at all difficult in the understanding of this. Professor Faraday was called upon to explain the table-turning, which many persons set down to electricity; but he was perfectly satisfied that this was a most untrue account of it, and that the explanation was (as, in fact, I had previously myself stated in a lecture at the Royal Institution) that the movements took place in obedience to ideas. Movements of this class are what I call "ideo-motor," or reflex actions of the brain; and the occurrence of these movements in obedience to the idea entertained, is the explanation of all the phenomena of table-turning. Professor Faraday constructed a very simple testing apparatus, merely two boards, one over the other, and confined by elastic bands, but the upper board rolling readily upon a couple of pencils, or small rollers; and resting on the lower board was an index, so arranged that a very small motion of this upper board would manifest itself in the movement of the index

through a large arc. He went about this investigation in a thoroughly scientific spirit. He first tied together the boards so that they could not move one upon the other, the object being to test whether the mere interposition of the instrument would prevent the action. He had three or four of these indicators prepared, and he put them down on the table so fixed that they would not move. He then put the hands of the table-turners on these, and it was found, as he fully expected, that the interposition of this indicator under their hands did not at all prevent the movement of the table. The hands were resting on the indicator; and when their involuntary pressure was exerted, the friction of the hands upon the indicators, and of the indicators upon the table, carried round the table just as it had done before. Now, if there had been anything in the construction of the instrument to prevent it, that would not have happened. Then he loosened the upper board, and put the index on, so that the smallest motion of the hands upon the board would manifest itself, before it would act on the table, in the movement of the index; and it was found that when the parties looked at the index and watched its indications, they were pulled up, as it were, at the very first involuntary action of their hands, by the knowledge that they were exerting this power, and the table then never went round. One of the strangest parts of this popular delusion was, that even after this complete exposure of it by Faraday, there were a great many persons, including many who were eminently sensible and rational in all the ordinary affairs of life, who said, "O, but this has nothing at all to do with it. It is all very well for Professor Faraday to talk in this manner, but it has nothing at all to do with it. We *know* that we are not exerting any pressure. His explanation does not at all apply to *our* case." But, then, Professor Faraday's table-turners were equally satisfied that *they* did not move the table, until the infallible index proved that they did. And if any one of these persons who *know* that they did not move the table, were to sit down in

the same manner with those indicators, it would have been at once shown that they did move the table. Nothing was more curious than the possession of the minds of sensible men and women by this idea that the tables went round by an action quite independent of their own hands; and not only that, but that really, like the people in the dancing mania, they *must* follow the table. I have seen sober and sensible people running round with a table, and with their hands placed on it, and asserting that they could not help themselves — that they were obliged to go with the table. Now, this is just simply the same kind of possession by a dominant idea, that possessed the dancing maniacs of the middle ages.

Then the Table-talking came up. It was found that the table would tilt in obedience to the directions of some spirit, who was in the first instance (I speak now of about twenty years ago) always believed to be an evil spirit. The table-talking first developed itself in Bath, under the guidance of some clergymen there, who were quite satisfied that the tiltings of the table were due to the presence of evil spirits. And one of these clergymen went further, and said that it was Satan himself. But it was very curious that the answers obtained by the rappings and tiltings of the tables always followed the notions of the persons who put the questions. These clergymen always got these answers as from evil spirits, or satisfied themselves that they were evil spirits by the answers they got. But, on the other hand, other persons got answers of a very different kind; an innocent girl, for instance, asked the table if it loved her, and the table jumped up and kissed her. A gentleman who put a question to one of these tables got an extremely curious answer, which affords a very remarkable illustration of the principle I was developing to you in the last lecture — the unconscious action of the brain. He had been studying the life of Edward Young the poet, or at least had been thinking of writing it; and the spirit of Edward Young announced himself one evening, as

he was sitting with his sister-in-law,—the young lady who asked the table if it loved her. Edward Young announced himself by the raps, spelling out the words in accordance with the directions that the table received. He asked, "Are you Young the poet?" "Yes." "The author of the 'Night Thoughts'?" "Yes." "If you are, repeat a line of his poetry." And the table spelt out, according to the system of telegraphy which had been agreed upon, this line,—

"Man is not formed to question but adore."

He said, "Is this in the 'Night Thoughts'?" "No." "Where is it?" "J O B." He could not tell what this meant. He went home, bought a copy of Young's works, and found that in the volume containing Young's poems there was a poetical commentary on Job which ended with that line. He was extremely puzzled at this; but two or three weeks afterwards he found he had a copy of Young's works in his own library, and was satisfied from marks in it that he had read that poem before. I have no doubt whatever that that line had remained in his mind, that is, in the lower stratum of it; that it had been entirely forgotten by him, as even the possession of Young's poems had been forgotten; but that it had been treasured up, as it were, in some dark corner of his memory, and had come up in this manner, expressing itself in the action of the table, just as it might have come up in a dream.

These are curious illustrations, then, of the mode in which the minds of individuals act when there is no cheating at all,—this action of what we call the subjective state of the individual dominating these movements; and I believe that that is really the clew to the interpretation of the genuine phenomena. On the other hand, there are a great many which we are assured of—for instance, this descent of a lady through the ceiling,—which are self-delusions, pure mental delusions, resulting from the preconceived idea and the state of expectant attention in which these individuals are.

Here are a dozen persons sitting round a table in the dark, with the anticipation of some extraordinary event happening. In another dark séance, one young lady thought she would like to have a live lobster brought in, and presently she began to feel some uncomfortable sensations, which she attributed to the presence of this live lobster; and the fact is recorded that two live lobsters were brought in; that is, they appeared in this dark séance—making their presence known, I suppose, by crawling over the persons of the sitters. But that is all we know about it; that they felt something—they say they were two live lobsters, but what evidence is there of that?—the séance was a dark one. We are merely told that the young lady thought of a live lobster; she said they had received so many flowers and fruits that she was tired of them, and she thought of two live lobsters; and forthwith it was declared that the live lobsters were present. I certainly should be much more satisfied with the narration, if we were told that they had made a supper off these lobsters after the séance was ended.

Now, it has been my business lately to go rather carefully into the analysis of several of these cases, and to inquire into the mental condition of some of the individuals who have reported the most remarkable occurrences. I cannot—it would not be fair—say all I could say with regard to that mental condition; but I can only say this, that it all fits in perfectly well with the result of my previous studies upon the subject, viz., that there is nothing too strange to be believed by those who have once surrendered their judgment to the extent of accepting as credible things which common sense tells us are entirely incredible. One gentleman says he glories in not having that scientific incredulity which should lead him to reject anything incredible merely because it seems incredible. I can only say this, that we might as well go back to the state of childhood at once, the state in which we are utterly incapable of distinguishing the strange from the true. That is a low and imperfect condition of mental

development; and all that we call education tends to produce the habit of mind that shall enable us to distinguish the true from the false — actual facts from the creations of our imagination. I do not say that we ought to reject everything that to us, in the first instance, may seem strange. I could tell you of a number of such things in science within your own experience. How many things there are in the present day that we are perfectly familiar with — the electric telegraph, for instance — which, fifty years ago, would have been considered perfectly monstrous and incredible. But here we have the rationale. Any person who chooses to study the facts may at once obtain the definite scientific rationale; and these things can all be openly produced and experimented upon, expounded and explained. There is not a single thing we are asked to believe of this kind, that cannot be publicly exhibited. For instance, in this town, I saw last week, a stream of molten iron coming out from a foundery; I did not see on this occasion — but the thing has been done over and over again, — that a man has gone and held his naked hand in such a stream of molten iron, and has done it without the least injury; all that is required being to have his hand moist, and if his hand is dry, he has merely to dip it in water, and he may hold his hand for a certain time in that stream of molten iron without receiving any injury whatever. This was exhibited publicly at a meeting of the British Association at Ipswich, many years ago, at the foundery of Messrs. Ransome, the well-known agricultural implement makers. It is one of the miracles of science, so to speak; they are perfectly credible to scientific men, because they know the principle upon which it happens, and that principle is familiar to you all — that if you throw a drop of water upon hot iron, the water retains its spherical form, and does not spread upon it and wet it. Vapor is brought to that condition by intense heat, that it forms a sort of film, or atmosphere, between the hand and the hot iron, and for a time that atmosphere is not too hot to be perfectly

bearable. There are a number of these miracles of science, then, which we believe, however incredible at first sight they may appear, because they can all be brought to the test of experience, and can be at any time reproduced under the necessary conditions. Houdin, the conjurer, in his very interesting autobiography — a little book I would really recommend to any of you who are interested in the study of the workings of the mind, and it may be had for two shillings — Houdin tells you that he himself tried this experiment, after a good deal of persuasion; and he says that the sensation of immersing his hand in this molten metal was like handling liquid velvet. These things, I say, can be exhibited openly, above board; but these spiritual phenomena will only come just when certain favorable conditions are present — conditions of this kind, that there is to be no scrutiny — no careful examination by sceptic; that there is to be every disposition to believe, and no manifestation of any incredulity, but the most ready reception of what we are told. I was asked, some years ago, to go into an investigation of the Davenport Brothers; but then I was told that the whole thing was to be done in the dark, and that I was to join hands and form part of a circle; and I responded to the invitation by saying that, in all scientific inquiries I considered the hands and the eyes essential instruments of investigation, and that I could not enter into any inquiry, and give whatever name I possess in science to the result of it, in which I was not allowed freely to use my hands and my eyes. And wherever I have gone to any of these spiritual manifestations, and have been bound over not to interfere, I have seen things which, I feel perfectly certain, I could have explained, if I had only been allowed to look under the table, for instance, or to place my leg in contact with the leg of the medium. And it has been publicly stated within the last month, that the very medium whom I suspected strongly of cheating on an occasion of this kind, was detected in the very acts which I suspected, but which I was not allowed to examine. I

cannot then go further into this inquiry at the present time; but I can only ask you to receive my assurance as that of a scientific man, who has for a long course of years been accustomed to investigate the curious class of actions to which I have alluded, and which disguise themselves under different names. A great number of the very things now done by persons professing to call themselves Spiritualists, were done thirty years ago, or professed to be done, by those who call themselves "Mesmerists;" thus the lifting of the whole body in the air was a thing that was asserted as possible by mesmerists, as is now done by Mr. Home and his followers. These things, I say, crop up now and then, sometimes in one form, sometimes in another; and it is the same general tendency to credulity, to the abnegation of one's common sense, that marks itself in every one of these epidemics.

Thus, then, we come back to the principle from which we started: that the great object of all education should be to give to the mind that rational direction which shall enable it to form an intelligent and definite judgment upon subjects of this kind, without having to go into any question of formal reasoning upon them. Thus, for example, is it more probable that Mr. Home floated out of one window and in at another, or that Lord Lindsay should have allowed himself to be deceived as to a matter which he admits only occurred *by moonlight?* That is the question for common sense. I believe, as I stated just now, that the tendency to the higher culture of the present age will manifest itself in the improvement of the next generation, as well as of our own; and it is in that hope that I have been encouraged on this and other occasions to do what I could for the promotion of that desire for self-culture, of which I see so many hopeful manifestations at the present day. When once a good basis is laid by primary education, I do not see what limit there need be to — I will not say the *learning* of future generations — but to their *wisdom*, for wisdom and learning are two very different things. I have known some people of the greatest

learning, who had the least amount of wisdom of any persons who have come in my way. Learning, and the use that is made of it, are two very different things. It is the effort to acquire a distinct and definite knowledge of any subject that is worth learning, which has its ultimate effect, as I have said, upon the race, as well as upon the individual.

But there are great differences as to their effects upon the mind, among different subjects of study; and I have long been of opinion that those studies afford the best discipline, in which the mind is brought into contact with outward realities, — a view which has lately been put forth with new force by my friend Canon Kingsley. You know that Canon Kingsley has acquired great reputation as an historian. He held the Professorship of History at the University of Cambridge for many years, and, in fact, has only recently withdrawn from it. Canon Kingsley also early acquired a considerable amount of scientific culture, and he has always been particularly fond of Natural History. Now, he lately said to the working-men of Bristol that he strongly recommended them to cultivate science, rather than study history; having himself almost withdrawn from the study of history, for this reason, that he found it more and more difficult to satisfy himself about the truth of any past event; whilst, on the other hand, in the study of science, he felt that we were always approaching nearer to the truth. A few days ago I was looking through a magazine article on the old and disputed question of Mary Queen of Scots, which crops up every now and then. She is once more put upon her trial. Was Mary Queen of Scots a vicious or a virtuous woman? The question will be variously answered by her enemies and by her advocates; and I believe it will crop up to the day of doom, without ever being settled. Now, on the other hand, as we study scientific truth, we gain a certain point, and may feel satisfied we are right up to that point, though there may be something beyond; while the elevation we have gained enables us to look higher still. It is like ascending a moun-

tain; the nearer we get to the top, the clearer and more extensive is the view. I think this is a far better discipline to the mind than that of digging down into the dark depths of the past, in the search for that which we cannot hope ever thoroughly to bring to light. It so happened that only a fortnight ago I had the opportunity of asking another of our great historians, Mr. Froude, what he thought of Canon Kingsley's remark. He said, "I entirely agree with it;" and in some further conversation I had with him on the subject, I was very much struck with finding how thoroughly his own mind had been led, by the very important and profound researches he has made into our history, to the same conclusion — the difficulty of arriving at absolute truth upon any Historical subject. Now, we do hope and believe that there is absolute truth in Science, which, if not at present in our possession, is within our reach; and that the nearer we are able to approach to it, the clearer will be our habitual perception of the difference between the real and the unreal, the firmer will be our grasp of all the questions that rise in the ordinary course of our lives, and the sounder will be the judgment we form as to great political events and great social changes. Especially will this gain be apparent in our power of resisting the contagious influence of "Mental Epidemics."

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10. Scientific Miscellany.

THE TIBER EXPLORATION.

ONE of the first results of the new life arising in Rome as a consequence of the downfall of the temporal power will be the realization of a scheme which has long been in contemplation, but which under the Papal government might, perhaps, never have gone beyond the limits of a wild and vague chimerical project — we mean the exploration of the bed of the Tiber. The Italians, who now, for the first time since Constantine, feel as if the great city were indeed their own, have an almost boundless, yet not exaggerated, idea of the artistic, archæological, and other treasures buried under the yellow sands which the river has accumulated on the spot for these last three thousand years. Every revolution, they say, had to pay its tribute to the river. It was the Tiber which received the statues of an unpopular emperor, his armor, and even his diadem and other insignia, even when the body itself was not flung into its waters. In more calamitous times, when Alaric, Genseric, Totila, or, in later ages, the Norman, the Swabian, the Austrian thundered at the gates, the inhabitants, hopeless for their lives, had no other means of baffling the invader's cupidity than by committing to the Tiber the spoils which must otherwise inevitably fall into the plunderer's hands. "The Tiber will have its own share," is a common saying among the Romans at the present day, and the universal receptacle of all that is lost has been further enriched by fires, inundations, wrecking of galleys laden with the wealth of the ancient and mediæval world, and the materials of ruined temples and palaces, of which the river afforded the most expeditious way of clearing the ground. We may imagine what wonders would gladden our eyes if we could bid the ocean restore whatever it hides

in its depths. But the Tiber flows over, if not as vast and rich, at least as interesting a variety of Old World relics, all lying undisturbed under fathoms of alluvial soil which has buried them for ages, and only awaiting the enterprising generation which will lay these long-forgotten treasures into the light of day.

The scheme of a thorough excavation of the bed of the Tiber, with a view to call the river to account and put it "in liquidation," compelling it to disgorge its ill-gotten gains, has now been taken up by an Italian association, at the head of which is the well-known Signor Alessandro Castellani; but which relies on the coöperation of many artists, antiquaries, and other learned men of Europe and America, all of whom have been strongly urging the speedy commencement of an undertaking which has already been too long delayed. It is not as a commercial or a financial speculation that the work is to be executed. Those who set about it expect no other return for their trouble and expense than the immense gain sure to accrue from it to art and history — to archæological knowledge in all its branches. The Society reckons, of course, on the aid of the other company, which has lately been formed with a view to protect the city from those periodical inundations of the Tiber against which the Papal government would, or could, find no remedy; and many of the contrivances by which our own engineers have laid the foundations of the Thames embankment will find their application in extensive operations which are now to be carried on along the banks and in the bed of the Roman river. Encouragement to the Italian Society in this truly great national undertaking comes in from every quarter, and a Parisian banking-house, of almost boundless wealth and munificence, has volunteered funds to defray the first expenses, so as to give the start to an enterprise which will certainly experience no lack of support in the sequel.

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II. The Geology of the Stars.

By PROFESSOR A. WINCHELL, of the University of Michigan.

THE present paper is intended to be less a disclosure of new facts in science than a grouping together of a certain class of modern results, all bearing directly on the problem of the history of a planet. Though geology, etymologically viewed, restricts itself to an investigation of the vicissitudes of our own planet, we have learned enough of the history and constitution of other heavenly bodies to demonstrate that the whole family of planets has had a common experience, and, in short, that every body in the visible universe belongs to one system of matter. Every one of these bodies is in some particular stage of an evolution which is no more characteristic of the earth than of Mars, or the sun itself, or Sirius, or the pale nebula on the farther verge of the universe. That kind of investigation, therefore, styled geological, extends itself to all the heavenly bodies; and the science of the earth becomes simultaneously the geology of the stars — the biography of worlds.

By a law of nature, every system of effects attains its completion through an evolution. No complex result comes into existence through single instantaneous causation. The plant *grows;* the animal *grows;* continents undergo a methodical *development*, and planets themselves have a history which we are able to trace with a degree of minuteness and certainty which excites the wonder even of science. To two laws of nature we are indebted for all knowledge of phenomena which do not pass under the observation of the individual or the race. The first is the law of evolution, or, to phrase it for our purpose, *the law of correlated successiveness, or organized history in the individual*, illustrated in the changing phases of every single maturing system of

results; as organic structure, human civilization, or world-making. The second is the *law of correlated simultaneousness, or parallel history in many individuals*, whereby many particular instances of progressive development, in different stages of maturity, are presented simultaneously; as the different persons in a large city exemplify simultaneously the stages of development attained by any individual on every day of his life.

Thus, by virtue of these two laws, each individual undergoing an evolution, finds, at every moment, its entire past and future recorded in the present of other individuals belonging in the same category. The man of mature years can turn in one direction and study the stages which he has passed through from earliest infancy; and in the other direction the stages which, in the course of nature, he will pass through to remotest old age. I go into the forest, and within an hour trace the life-history of an oak all the way from the acorn to the crumbling veteran of three hundred years. An ephemeron intelligence could thus write the history of a tree destined to endure a thousand years. It is so in the history of a planet. Man is an ephemeron compared with the life-time of a world; but while he endures, he notes thousands of worlds in all the different stages of world-life, and, selecting a series of examples, he runs them on a continuous thread, and has a tale of evolutions which span a million years. Individual histories have been begun at different periods in the lapse of time; and individual histories, whether simultaneously begun or not, have been accelerated or retarded by differences in the modifying conditions.

Our earth has reached a certain stage of development; it happens at this epoch to be a habitable world. It is supposable that its present state has persisted from eternity; and this was the belief of some of the ancients, as well as a few of the moderns. Limited observation, however, shows that changes are transpiring — that a history is in progress; and the mind demands the past of this history — that which

lies back of the observation of the individual, or even of the race. Now, availing ourselves of the *law of parallel history*, we study the phenomena of beach erosion and detrital accumulation, and see in these a picture of Silurian times — of geologic changes consummated thousands of years before even our race had an existence. This is pure geology. But nothing in the existing phases of the planet can reveal the history of events which *transformed* the planet. Bodily transformations obliterated all records of what was past. Geology has perpetuated terrestrial history only by the fixed forms of enduring rocks. But we find in igneous masses intimations of an older state, whose records were written upon fluid matter, to be inevitably effaced. Here is the limit of possible geology. But we learn that our earth, as a whole, is but one of a series of planets; that these planets have had a *common* history; that before they were planets, they belonged to a category of existence of which the sun is a type and a remnant; that probably, in some remoter epoch in the past eternity, all the suns belonged to a category of existence now exemplified in irresolvable nebulæ; and we learn that all these conditions are phases in the consummated history of our world — that the investigation of them is at the same time cosmogony and geology.*

Let us glance at the data of this comparative science of world-growth. The first group of data unites the earth, the planets, and the satellites in a single category of existence. What are the phenomena? All the planets revolve about the sun. They all revolve in one direction — from west to east. They all revolve approximately in one plane — the ecliptic. Their orbits are all ellipses, and all have one of their foci at a common point occupied by the sun. They all move with accelerated velocity in perihelion, and retarded velocity in

* Almost while we write these words a somewhat remarkable book from Paris reaches our hands. M. Stanislas Meunier has also been discussing this subject in a work entitled *Le Ciel géologique, prodrome de Géologie Comparée*, Paris, 1871.

aphelion, so that the radius vector of each planet — or the line stretched from it to the sun — sweeps over equal areas in equal times. Their periods of revolution increase regularly as their distances from the sun increase; and this relation is so exact that we say the squares of the periodic times are as the cubes of the mean distances from the sun — the planets thus lengthening their periodic times not only by a lengthening of their orbits, but by a slackening of their velocities. There are known eight major planets, and, at the present moment, one hundred and thirty-one * asteroids, or minor planets, all conforming essentially to these conditions, and thus testifying to the presence of a common actuating power throughout the limits of the system.

Besides these planets we know of twenty-two satellites, or secondary planets, revolving about their primaries. These also perform their revolutions under the same laws as the primaries, and thus reveal the supremacy of the same physical government. We ought, however, to note that the satellites of Uranus present an exceptional degree of obliquity to the plane of the planet's orbit. In fact, the plane of the satellites is tilted up at an angle which exceeds the perpendicular by about eleven degrees; thus the whole system is nearly *inverted*, and the motion of the satellites, like that of the hands of a watch, lying face downward, seems to be reversed. A moment's reflection will convince us, however, that this is an illusion. The motion is normal; the attitude of the system only is extraordinary. As the satellite of Neptune presents, similarly, a retrograde movement, we must attribute the facts, similarly, to an inversion of that system.

In the next place, so far as we have been able to ascertain, every body belonging to our system is actuated by a rotation

* The 118th was discovered March 15, 1872, by Luther, of Bilk; the 119th, April 3, by Watson, of Ann Arbor; the 120th, April 10, by Borelli, of Naples; and the 121st, May 12, by Watson.

upon its axis. To this law the sun itself is not an exception. These rotations, moreover, are all from west to east, though it is probable that the axis of Uranus is partially inverted, and that the planet would present an illusory retrograde movement of rotation.

Finally, the spheroidal form characterizes every body of our system. If, as is conjectured, any of the minor planets exhibit an angulated contour, we shall be able to attribute this to an accidental cause.

This community of conditions — this unanimous obedience to one code of physical laws — implies that all these bodies are urged onward through a common history, and have probably had their starting-point in one common state of matter. These indications have attracted the attention of philosophers from the time when Kepler and Newton established the laws of the solar system. Leibnitz,* Kant,† Lambert, ‡ and Bode, § felt compelled to believe that the family of planets had been as intimately united in their origin as they are in their allegiance. The elder Herschel was deeply impressed by these family characters; and, having made the acquaintance of a form of matter which exhibited the chaotic state to which all cosmogonies, from time immemorial, have traced the history of the world, he threw his conjectures into somewhat definite shape. ‖ The irresolvable nebulæ seemed to him the primitive world-stuff — *discordia semina rerum;* and Laplace, then fresh from his im-

* Leibnitz, *Protogæa, sive de prima facie Telluris*, etc. 1683; Buffon, *La Théorie de la Terre*, and *Époques de la Nature.*

† Kant, *Allgemeine Naturgeschichte und Theorie des Himmels*, 1751; Helmholz, *Interaction of Natural Forces*, Youmans ed., p. 230.

‡ Lambert, *Cosmological Letters.*

§ Bode, *Kentniss des Himmels.*

Leucippus of Miletus held that the earth was disengaged from a chaos of matter which spontaneously assumed a vortical movement in a vast vacuum. Diog. Laer., *Lives* (Bohn's ed.), p. 389.

‖ Herschel (Sir William), Philosophical Transactions, 1811.

pressive demonstrations of the harmony of the "System of the World," adopted the suggestion (if it was not also original in his own mind), and gave it elaboration.

That all the bodies of the solar system should have proceeded from a common origin seems no more probable than that such origin should have been what Herschel and Laplace suggested. They thought the matter of the system had existed originally at such a temperature as to be in the condition of a vapor of great tenuity, stretching across limits wider than the orbit of the remotest planet. The cooling and contraction of this vapor inaugurated a rotation which was inevitably accelerated to such an extent that a peripheral ring was detached, which became a planet. The same process continued, and other rings were detached, which became the other planets, in due succession. Similarly, the planetary masses detached rings which became their satellites. Thus all the marvellous uniformities of the solar system are but the progeny of that primitive impulse which originated the grand rotation.*

We said this account of planetary genesis was but an hypothesis. So was the doctrine of universal gravitation a hundred years before. This doctrine has earned unquestioning acceptance, simply because it accords with all the phenomena; and the nebular hypothesis, for similar reasons, is rapidly taking its place among established doctrines. Many late discoveries afford unexpected confirmations; and there are few physicists at the present time who continue to withhold their assent. Occasionally we hear a dissenting voice; but it proceeds, almost always,† from persons who,

* For a popular detail of these events, and others connected with the early history of the world, see the writer's *Sketches of Creation*, 1870.

† Proctor is the only scientific authority, of very recent date, who seems disinclined to the nebular doctrine. (See *Other Worlds than Ours*, pp. 220–9); but one cannot help feeling that the doctrine might fare better with him, had he no hypothesis of his own to

whatever their eminence in theology * or letters, have little authority in matters of scientific opinion.

Many interesting deductions follow from the nebular origin of the solar system. The older planets are those remoter from the sun, and the youngest planet is Mercury; while the sun is only the residual portion of the cosmical mass, still maintaining an inconceivably high temperature, *simply because so vast a body of matter has not yet had time to cool off.*† The planetary bodies, similarly, must have attained to stages of refrigeration determined by the joint influence of age and mass. It is reasonable to suppose that the older planets are composed of a smaller proportion of the denser elements than the newer planets, since they are formed from peripheral portions of the original fire-mist, while it is likely that the denser portions gathered about the centre, and entered, to a larger extent, into the constitution of later rings. The lower specific gravity of the older planets may be partly attributed to this cause. While Mercury, Venus, and Mars do not vary materially from the density of the earth, Jupiter, Uranus,

chaperon into popularity. The reader will also find it opposed in Professor Martyn Paine's *Physiology of the Soul and Instinct, as distinguished from Materialism*, 1872. But Dr. Paine also *denies the correlation of physical forces*, and maintains *the modern creation of the world in six literal days*, and *the absolute universality of the Mosaic deluge.*

* Hear the testimony of Father Secchi, S. J., of the "Roman College:" Les savants sont de nos jours *unanimes* à admettre que notre système solaire est dû à la condensation d'une nébuleuse qui étendait autrefois au-delà des limites occupées actuellement par les planètes le plus lointaines."—*Le Soleil*, p. 332. "La théorie . . . a été bien confirmé, et, pour ainsi dire, demonstré par la découverte des nebuleuses gazeuses."—Ibid., p. 401.

† Mayer's theory (*Celestial Dynamics*, Youmans' ed., pp. 264-282), recently so popular, that the solar heat is maintained by the precipitation of meteoric matter, is now entirely abandoned, since Sir William Thomson demonstrated that it implies such an addition to the mass of the sun as would have retarded the movement of the earth one eighth of a year in the interval of two thousand years.

and Neptune possess only one fourth of the earth's density, and Saturn but one eighth. This circumstance must have much to do with determining the relative proportions of solid and liquid materials upon the several planets at given temperatures, and is thus connected with their adaptability to serve as abodes of organic life. Aside from the question of the relative abundance of solids and fluids, every planet, since it must pass through the same succession of states, must attain, at some time, the habitable state. With some of the planets, that state may be passed; with others, it may be still in the future. The question, indeed, arises, whether the solar light and heat of the remoter planets are sufficient to sustain such life as populates our globe. Other things being the same, these are not sufficient. Mars receives $\frac{4}{9}$ as much light and warmth as the earth; Jupiter, $\frac{1}{25}$; Saturn, $\frac{1}{91}$; Uranus, $\frac{1}{400}$; and Neptune, $\frac{1}{1000}$. But, as others have often suggested, the greater density of their atmospheres would more effectually arrest radiation of heat from those planets; and two other suggestions may be added. First, there must be a time in the history of every planet, whatever the deficiency of solar heat, when the warmth contributed by the planet would adequately supplement that afforded by the sun. Secondly, in the case of the remoter planets, whose habitable stage would be coeval with a higher surface temperature, there would be, accordingly, a greater amount of aqueous vapor in the atmosphere, which, as meteorology has shown, would act as a blanket to retain the warmth in the subjacent stratum of air. The solar light on the remoter planets is supplemented by numerous moons, and must, at least, be equal to that of the deep waters and dusky terrestrial situations to which numerous forms of life are found especially adapted. Finally, it is in accordance with all known analogies, that every spot should be utilized for the purposes of life.

The majority of the fixed stars, we may fairly conclude, are really other suns, as astronomers long since conjectured;

and, being such, it is almost certain that many of them are encircled by planets in all stages of development, from the self-luminous to the wholly refrigerated; and that thousands of these planets must at this moment exist in conditions analogous to those of our earth; and, finally, that they are the abodes of organic creatures and thinking intelligences. How it dissipates the cold cheerlessness of the depths of space to conceive them teeming with forms of intelligent organization, gathered about comfortable homes, exchanging sympathies, and casting glances of curious interest towards the stars of *their* firmament, amongst which our sun may be mapped as a star of the third or fourth magnitude! However we may be lacking in data for thinking them bodies and physical surroundings, we are certain, as will presently be shown, that their worlds are all made of the same substances as our rocks, and water, and air, and that their organizations must be adapted to the same physical laws. Most of all are we certain that *intelligence* is the same there as here. The same intelligible relations dominate throughout the material universe; and as we cannot suppose an intelligence to which those relations must not be correlated as they are to us, it follows inevitably that those distant denizens of our common universe must *understand* things as we understand them; and that, if such distant intelligences could be brought together, each stripped of the adventitious characters which adapt it to its peculiar abode, they might at once enter into relations of sympathy and friendship, like newly-discovered cousins from distant countries.

That the planetary nebulæ — circular or annular nebulæ showing one or two brilliant central nuclei — are world-stuff in a partial state of condensation, is another deduction from the nebular doctrine. It is equally certain that the irresolvable nebulæ are modern examples of primary world-stuff; while the resolvable nebulæ may either be external firmaments, as Sir William Herschel at first conjectured, or masses of nebulous matter within our firmament, in the act of

assuming the discrete condition, by aggregation about local nuclei, in accordance with the speculations of Laplace.

We turn, now, to another group of data — the physiographic features of the planetary surfaces. What can we discern in the exterior conditions of the planets and satellites to suggest analogies with our earth, or reflect a light upon either the past or the future? The moon being removed from us but ten times the circumference of the earth, we ought to expect much from a telescopic study of that body. We learn, first of all, that neither water nor atmosphere is present. Hence the moon is not inhabited. Its surface is diversified by mountains and valleys, which are visible even to the naked eye. With the aid of astronomical instruments, we learn that some of the lunar mountains attain Andean altitudes, and that the surface of the moon is wonderfully intersected by deep, dark gorges, which look less like valleys than immense fissures formed in the body by a shrinkage of its mass. Some of the mountains assume the forms of volcanic cones, and vast crater-like openings yawn in their summits. Occasional plains spread out in the midst of the rugged relief of the lunar surface, but they are of limited extent, and, though formerly supposed to be water, are probably nothing more than areas underlaid by sedimentary rocks. They are, then, attestations of the former presence of water, at least in limited amount; and, if lunar sea-waters ever accumulated sediments, they must have acted upon their shores to obtain the material. Such action may have arisen, to some extent, from tidal movements, without an atmosphere; but the narrowness of the seas is incompatible with any considerable tides; and, in the present condition of things, no tidal action could arise from the influence of the earth, since that is exerted always upon one side of the moon. The only cause of tides, therefore (if the present attitude of the moon represents all the past) was the solar attraction; and when we consider that two weeks intervened between high and low water, it is apparent that the erosive action must

have been very trifling. Sedimentation on the moon, therefore, must probably have been caused by erosive movements of the water, *excited by winds.* This implies an atmosphere. But the former existence of a lunar atmosphere, as well as of lunar seas, is a fair and direct deduction from the doctrine of the common origin of the earth and moon. Elements entering so largely into the constitution of our earth must, certainly, have existed upon the moon.

But if water and air have existed upon the moon, how shall we explain their disappearance? They have been absorbed by the rocks. Consider that in the present condition of our globe, the water and air must be unable to penetrate more than one fiftieth the distance to the earth's centre. Percolating downward through the rocks, the water soon reaches a temperature which dissipates it into vapor, and returns it towards the surface, to be recondensed. Thus a circulation is maintained analogous to that which existed in the atmosphere in the early history of cloud and rain formation, while yet the lower strata of the atmosphere were too highly heated to permit the existence of water. But, as in the earlier age, the progressive cooling of the earth will allow the waters to circulate deeper and deeper. When the thickness of the terrestrial shell which must be saturated with water, has doubled, the increased demand must lower the waters of the ocean; and, long before refrigeration has reached the centre, the thirsty rocks will have swallowed the sea and all our surface waters. The drained, and shrunken, and shivered zone lying nearer the surface will suck in the atmosphere, and this will disappear in the pores and caverns of the worn-out world.*

The total disappearance of water and air from the surface

* M. Sæmann has shown (*Bulletin de la Société géologique de France*, February 4, 1861, translated in *Canadian Naturalist*, Vol. VI. p. 444, December, 1861, and *American Journal of Science*, [2] XXXIII. 36, January, 1862) that the pores of the rocks, on the total refrigeration of the earth, would drink up *one hundred times* the

of the moon may therefore be assumed as evidence of an advanced stage of refrigeration. The moon is a fossil world — an ancient cinder suspended in the heavens, once the seat of all the varied and intense activities which now characterize the surface of our earth, but in the present period a realm of silence and stagnation. Sprung from the bosom of the earth, there was a time when its physical condition had not diverged from that of the earth, ; but swung by itself in the midst of frigid space, and having but $\frac{1}{49}$ the bulk of the earth for the conservation of its temperature, cooling proceeded forty-nine times as rapidly as that of the earth. Its geological periods were correspondingly shorter. Its zoic age was reached while yet our world remained, perhaps, in a glowing condition. Its human period was passing while Eozoön * was solitary occupant of our primeval ocean. The lunar days were not then, as now, of four weeks' duration. The earth had not yet, by its perpetual strain upon the unequally-balanced mass, *set* the lunar orb, as it were, in the cerulean vault, with the same face always turned towards our globe. Its day was probably much shorter than ours. In the progress of time, the powerful attraction of the earth would gradually draw the heaviest side towards itself, and eventually fix it in that attitude.† The waters, already in excess

whole amount of water in the oceans, and that the unfilled pores would more than suffice for the retirement of the atmosphere.

* If Eozoön ever had a real animal existence. The question, always kept open by some of the Irish geologists, has lately been raised in America by Messrs. Burbank and Perry. See *Proc. Boston Soc. Nat. Hist.*, 19 April, 1871, Vol. XIV. p. 189.

† It seems eminently improbable that, on the first disengagement of the moon from the terrestrial mass, it should have had imparted to it an axial rotation exactly synchronous with its orbital revolution. This correspondence is so precise that it must have been determined by the influence of the earth, as a secondary result. The result is demonstrable, as a physical necessity, in the case of any orbital movement by an axially rotating body not precisely balanced upon its centre of rotation. The phenomenon may be illustrated by a wheel

upon the opposite side, would now still farther retreat to that hemisphere. The limited tracts of sedimentary rocks upon the hither side of the moon are probably not the only traces of water which would be discerned if we could inspect the further side. This was at least one of the crises in the life of the planet. It was no longer habitable. The populations which had lived and thought upon its surface had fulfilled their appointed destiny, and exchanged their corporeal habiliments for spiritual instrumentalities of another order. Ages after, when our planet had become fitted for intelligent organizations, the moon's surface had already become desolate — an abandoned camp — a ruined habitation, perpetuated only to admonish the earth of her own impending fate, and teach her occupant that other home must be provided which frost and decay can never invade.

Next to the moon, Mars is the planet whose physiographic features are most clearly revealed by the telescope. We have here indications both of seas and atmosphere. The winding shores of vast continents, the deep bays and long-drawn inlets reveal a disposition of land and water analogous to what we witness upon the earth. The climatic indications

eccentrically hung and set to revolving. If left to itself, the motion becomes more and more unequal. The heavier side, drawn continually towards the earth, is accelerated when moving down, and retarded when moving up. Continual friction, destroying the *vis viva*, makes the rotation continually slower, until at length the heavier side fails to attain the requisite elevation; its motion ceases, and it is drawn backward, and thus commences a series of simple oscillations ever diminishing until they cease, and the wheel hangs, like the moon, with its heaviest side towards the earth. In the absence of all friction, an unequal rotation might be perpetuated indefinitely; but friction must have acted energetically upon the moon, through the tides, which were as much greater than our lunar tides as the earth exceeds the moon in mass, diminished, however, by the inferior width and depth of the lunar seas, but increased in retarding efficiency by their more rapid flow consequent on the (probably) more rapid rotation of the moon.

are such as would be anticipated from the inclination of the planet's axis and its other astronomical relations. The four seasons follow each other in regular succession. Eternal winter reigns at either pole. A shining cap of snow marks the polar regions, and this is seen to advance towards the temperate zones, and retreat, with the vicissitudes of the seasons. Clouds sometimes gather over the planet's disk, obscuring the features of the land, and storms have been witnessed * presenting the phenomena of an afternoon shower in the latitude of Boston. Still, no satisfactory indications of vegetation have been detected, and there are reasons which prevent us from feeling confident that this planet has not passed its habitable stage. Its diameter is little more than half that of our earth, and its bulk is little more than one seventh. Reasoning, then, as Sæmann has done in the case of the moon, this planet's geological periods must have been but one seventh the duration of the earth's, and its organic phase — at least its phase of highest organization — should have passed. But though it cannot be doubted that the ratio of the times of total refrigeration of two planets would nearly equal the ratio of their volumes, it is still worthy of consideration whether, on acquiring a crust having a thickness of (say) one hundred miles, the surface temperatures of two planets must not be substantially identical, so far as they depend on internal heat; and if so, whether corresponding surface revolutions must not thereafter have nearly equal periods on the two planets. Such a crust would transmit central heat with equal rapidity on a small planet and a large one; and it may well be doubted whether even *geological revolutions determined by superficial and sub-superficial temperatures* might not succeed each other by equal intervals upon the large planet and upon the small one. Let us grant

* Lockyer, *Mém. Roy. Astron. Soc.*, Vol. XXXII., p. 183. On the analogies of Mars and the Earth, see Proctor, *Other Worlds than Ours*, Ch. IV.

that the larger one would require a longer period to begin solidification, and to thicken its crust to such an extent that the further loss of internal heat would be exceedingly slow, as in the case of the earth; it would seem that after this condition is attained, each planet would go forward in its revolutions with nearly equal steps. But as the smaller planet would sooner reach the stage of incrustation, thus, also, however retarded the process of radiation might become, solidification would sooner reach the centre of the smaller globe than that of the larger.

We conclude, therefore, that the question of the present habitability of Mars must remain open. That the habitable phase is embraced in the programme of its history we can scarcely doubt; and it is a pleasing and not a useless occupation to indulge in speculations in reference to the possible natures of intelligent and unintelligent beings, which may have fulfilled or now fulfil the functions of inhabitants of another world lying in the depths of space.*

When we lift our eyes to Jupiter, lying beyond the populous zone of asteroids, a strongly contrasted scene presents itself. Here are no outlines of continents and oceans, but only a series of changing belts, which are clearly phenomena of a medium of great mobility. It seems to be the general opinion that all we see of Jupiter is a perpetual envelope of clouds. These must float in an atmosphere at a very considerable elevation above the body of the planet, and thus occasion an exaggerated judgment of its bulk, and a diminished estimate of its density.

* The doctrine of the habitability of other worlds has been advocated and opposed by writers of learning and eminence. Among the ablest of the opponents are Brewster (*More Worlds than One*) and Whewell (*Plurality of Worlds*). One notices that a good deal of opposition to the doctrine seems to have grown out of its supposed relations to orthodox theology; but it is certainly a great weakness to allow a theological dogma to bias the judgment upon a purely scientific question.

How shall we explain this permanent envelope of watery vapor? The explanation is easy; for this is one of the phases which every planet must present in the progress of its cooling. A time arrives when the upper regions of its atmosphere first attain the temperature which condenses the vapor of water. During a cosmic period, the clouds accumulate, slowly shutting out the light of the sun, and copiously discharging their rains towards the planet. The rains, penetrating the lower strata of the atmosphere, are converted to vapor and returned to the clouds, to be again condensed and precipitated. Every ascending particle of vapor carries off a portion of heat from the atmosphere, and promotes the cooling of the planet. But cosmic changes are slow, and ages must elapse while a tempest rages in mid air, which is quite unfelt upon the surface of the planet, save as the vivid lightnings shed a violet gleam over the arid surface or the rolling thunders mark the time of the tempest's march. Gradually the line of conflict settles towards the heated crust. At length the rains strike the crust. Then, after a period of increased excitement in the elements, a universal ocean begins to accumulate — a boiling, steaming, turbid ocean. After a further lapse of ages, the cooling and accumulating waters lead to signs of exhaustion in the clouds. Light filters feebly through, and the lowest organisms appear in the sea. Then the clouds break, and full sunlight and peaceful elements are the signal for advancing grades of organization.

Such a scene has been witnessed upon our own planet; such a storm seems to be raging to-day in the heavens of Jupiter. We gaze upon the shifting shadows of his long-drawn cloud-belts; we imagine the tempest which is raging under their cover, and can almost fancy we see the cloudy mass lit up occasionally by an electric gleam. Here is a picture of an age long gone by in the history of the earth. Here is a stupendous object-lesson, which, like the curdled fire-mist which engirts the sun, demonstrates an ancient state

of terrestrial things, to the knowledge of which man could never possibly attain either by history or tradition, or even the uncorroborated testimony of the rocks.

Is it demanded how a planet so ancient as Jupiter can be in this condition, while Mars, Earth, and Venus, so much younger, have long since passed their stormy epoch? We answer, the mass of Jupiter is so great that a larger period must be consumed in his refrigeration. The sun is older than the remotest planet, and has not yet attained even the stage of Jupiter. As Jupiter is a thousand times the volume of the earth, the sun is a thousand times the volume of Jupiter. The "giant planet" seems hardly to have lost his inherent luminosity. He shines with a stronger light than could be expected — stronger than if his surface were covered with snow. He seems, indeed, to emit, as some think, even more light than he receives. Mars reflects but one fourth the light received from the sun, and the moon but one fifth. Even if, according to others, the light emitted by Jupiter is only three fifths as intense as total reflection of the solar light would render it, this, judging from the reflective capacity of Mars and the moon, implies that half his light is his own. Verily the clouds must be in the earliest stage of condensation about this planet, or the lightnings are really producing such an illumination as in fancy we saw.

In Saturn we discover a planet, which, if we may trust the determinations, is even lighter than water. No surface-features of the body of this planet are discernible, and it seems, like Jupiter, to remain enveloped in a mass of belted clouds. Its most striking phenomena are its eight satellites and its grand system of rings. The first thought suggested by the latter is their demonstration of the truth of the nebular theory of planetary origin. Here we have, as a visible fact, a perpetual instance of the ring-condition — a demonstration even more convincing than the laboratory experiment of Plateau. Is this planet, then, in a more primitive condition than Jupiter, at once the younger and the larger

body? An affirmative answer is indicated both by the rings and the low specific gravity; and the intensity of its light, making allowance for greater distance and inferior bulk, is almost equal to that of Jupiter. But the substance of the ring is not aeriform, as we suppose the normal ring-condition to be. It is neither solid nor fluid, as Professor Pierce has demonstrated, but, according to a suggestion of Proctor, may be in a granular state — each constituent grain (so to speak) answering to a miniature moon, and the whole assemblage, millions in number, disposing themselves, according to the varying influences, in two, three, or more annuli. The rings, then, are not formative rings in their normal state, but normal rings chilled in the act of transformation, — like the embryos of animals preserved in alcohol, — and not less intelligibly than these, adapted to educational ends.

Thus the present state of the solar system is a living picture of the entire history of a single planet. From the solar fire-mist to ring-girt Saturn — from Saturn to storm-beaten Jupiter — from Jupiter to the sunny summer time of our own planet — from Earth to autumn-browned Mars, and from Mars to the wintry silence and desolation of the dark gulches of the Moon, — here is a series of stages which carry thought back into the eternity long lapsed, and onward into the measureless depths of the future, and confer upon human intelligence a sort of exemption from the limitations of finite existence.

Let us now appeal to a third class of facts as grounds for generalizing the history of matter. The spectroscopic revelations of the last few years have lifted a fog from the heavens, and given us a deeper insight into the constitution of the universe than the boldest imagination had dared to anticipate. The spectroscope is a little instrument which works with a magical power. It takes the slender beam of light admitted through a narrow slit in the window-shutter, and subjects it to a peculiar analysis. It translates the impressions left upon the ray by the experiences of its past

history — as if the magician should gaze in a man's face, and discern there the lineaments — the ineffaceable records of the history of the soul — the moment of delight — the hour of anguish — the storm of passion, or the indelible stamp of crime. It puts the solar ray upon the rack, and extorts a full confession of the secrets of its origin and its flight through space. By what appliances this knowledge is extracted we need not here explain.* The confession is written in lines of light and darkness upon a screen — a sort of telegraphic language, traced by mysterious manipulations millions of miles across the depths of space.

Now, what are the revelations extorted from the beam of solar light? First, the *dark* lines of the spectrum proclaim the existence, in the sun, of a luminous solid or liquid body, shining through vapors or gas. The natural conclusion is, that the nucleus of the sun is a molten globe which shines through one or more gaseous or vaporous envelopes. Next, the *bright* spectral lines afforded by the solar protuberances demonstrate a condition of gaseity; and finally, the reversal of the Fraunhofer lines in a spectrum close to the photosphere (as first noted by Professor Young in 1870), that is, the substitution of bright lines for dark, in the spectrum of

* Elementary information is now very accessible in the writings of Roscoe, Schellen, Huggins, Lockyer, and others. Roscoe's *Spectral Analysis* has been republished in this country, as well as a translation of Schellen's magnificent and admirably posted work, *Die Spectralanalyse.* In spectroscopic discoveries, our countryman, Professor C. A. Young, of Dartmouth College, stands honorably conspicuous.

We append here only the three fundamental principles of spectral analysis: 1. *The spectrum of an incandescent solid or liquid is* CONTINUOUS, i. e., *it presents no lines across it.* 2. *That of a glowing vapor is crossed by numerous* BRIGHT *lines; and each different vapor gives a different set of bright lines.* 3. *That of an incandescent solid or liquid shining through a vapor (dark or incandescent) is crossed by numerous* DARK *lines; and these occupy the same positions as the bright lines proper to the spectrum of the vapor.*

that layer, indicates there, also, the presence of a luminous vapor. This reversal of the lines has also sometimes been seen in the neighborhood of the solar "spots." Uniting the services of the telescope with those of the spectroscope, the most probable constitution of the sun seems, at present, to be as follows: 1. A central, liquid, intensely luminous *nucleus*.* 2. A *non-luminous zone*, charged with mineral emanations from the nucleus, which, perhaps, like super-heated steam, exist at too high a temperature for visibility. 3. The *photosphere*, a visible fire-mist, or metallic fog, analogous, probably, to the cloud-condition of water.† 4. A narrow zone of intensely *bright matter*, the existence of which is affirmed by Secchi, Proctor, and others, though the question is not fully settled. 5. The rose-red *chromosphere*, or sierra, in which exist the solar "prominences," or "protuberances," rising sometimes a hundred thousand miles above the general surface, and demonstrated by the spectroscope to consist of glowing hydrogen, with a small admixture of sodium, magnesium, and barium, if not other elements. 6. The *outer chromosphere*, or *inner corona*. 7. The *outer* or *radiated corona* streaming out one or two millions of miles from the photosphere. Whatever may hereafter be proven as to the structure of the sun, it is admitted on all hands that we have in it an incandescent mist or vapor, such as the nebular doctrine requires, and such as fully exemplifies the supposed primordial condition of each of the planets.

Secondly, the combinations of the dark lines of the spectrum spell out the names of more than a dozen chemical elements, which must enter into the constitution of the sun,

* Father Secchi has argued strongly in support of his theory of a gaseous, intensely-heated, but non-luminous interior (*Le Soleil*, pp. 104–6); and M. Faye has elaborated the same view (*Comtes rendus*, 16 and 23 January, 1865, and 27 July, 1868, Tom. LXVIII. p. 197).

† Physicists are generally agreed in this view, first suggested by Scheiner and Wilson, and adopted by Sir William Herschel.

and which make up, also, a large proportion of the substance of our earth. Sodium, iron, hydrogen, magnesium, barium, copper, zinc, calcium, chromium, nickel, cobalt, and titanium are certainly present, and strontium, cadmium, and potassium are probably associated with them. Now, sodium is the basis of common salt, and hence forms a large percentage of sea-water, besides being generally disseminated through the rocks. Iron and manganese are of almost universal distribution through the crust of the earth. Calcium is the basis of all limestones, marble, and chalk, as well as an abundant constituent of other rocks. Hydrogen constitutes one eighth of all the water of the world, besides entering into the constitution of coal, asphalt, petroleum, and other mineral products.

All this is as it should be, if the sun is the mother of all the planets. The earth is but a specimen of cosmical matter, which, like a lump of chalk in a museum, exemplifies the constitution of masses of matter removed from actual inspection, perhaps by impassable intervals of space.

The spectroscope has been turned also to the analysis of stellar light. Now, the very fact that starlight has reached us implies the continuity of the luminiferous medium between the stars and the earth. How much this signifies may be indicated by the fact that light, which goes seven times around the earth in a second, requires three years and a half to reach us from the nearest star, and eight thousand years to arrive from the remotest star having a sensible parallax; while tens, if not hundreds, of thousands of years are required for its journey from the remotest nebulæ. Yet the same ether pulsates upon worlds thus widely separated, as the waves of a common ocean beat upon the shores of distant continents. What has the spectroscope to testify of the nature of stars and nebulæ? If the world has descended from states of matter perpetuated in those distant realms, we must search their archives for the earliest monuments of

geological history, as we go to the fatherland to study the genealogy of American families.

Little as the stellar bodies differ from each other to unassisted, or even to telescopic vision, the delicate analysis of the spectroscope reveals a wide disparity. A certain class of the stars presents a spectrum identical with the ordinary spectrum of the sun. These are the *yellow* stars, — the second type of Secchi, — comprising about one third of the whole number, and including Aldebaran, Arcturus, Pollux, and Procyon. The dark lines which they afford reveal the presence of sodium, iron, hydrogen, magnesium, calcium, bismuth, tellurium, antimony, and mercury — a marvellous catalogue to make up from the study of matter so remote that its direction is sensibly the same when viewed from points one hundred and eighty-four millions of miles distant from each other.

The *white* stars, — the first type of Secchi, — which make up about one half of the entire number of stars, present an identical spectrum, except that the *greater pressure* of the absorbent medium produces broader dark lines; and we are thus led to infer a deeper photosphere. This may result from a larger stellar mass, or a more advanced stage of condensation, or photosphere formation. Sirius, Vega, Altair, Regulus, and Rigel are examples of this class.

Most of the *variable* stars — the third type of Secchi — of which the most remarkable number about thirty, afford spectra nearly identical with those of the yellow stars; but they present, also, a large number of nebulous bands — characters which, according to Father Secchi,* are also afforded by the spots upon our sun. From this correspondence he argues that their variability is due to a very great prevalence of "spots." Accordingly, our sun, as already indicated from the periodicity of its spots, would be *a variable star;* and we may add, that the abundance of the spots

* Secchi, *Le Soleil,* pp. 393, 395.

must sustain some relation to the stage of condensation of the mineral emanations from the nucleus. Advanced condensation would deepen the photosphere, enlarge the molten nucleus, and thin the dark zone, and thus, probably, diminish the maculations; since if, as seems probable, the spots reveal the action of solar storms, their frequency and extent would diminish with the diminution of the contrast of temperatures in contiguous solar envelopes. We might therefore conjecture that our sun represents a somewhat more advanced stage of stellar life than that manifested in the more variable stars. On the contrary, it may be suggested that the more advanced stage would be characterized by a more exhausted photosphere and increased maculations. Among the stars of this class Beta Pegasi gives lines indicating the presence of sodium, iron, magnesium, calcium, and bismuth.

The *red* stars, — the fourth type of Secchi, — about thirty in number, offer a spectrum which, while characterized by dark lines, indicative of a state approximating that of the sun, presents, on the whole, an *ensemble* indicative of a higher state of gaseity; * and we are hence led to suggest that these stars may represent an earlier stage than any of the others. Only carbon has been certainly identified in the spectrum of the red stars.

Most of the resolvable nebulæ, being mere clusters of stars, present, as we should expect, ordinary spectra. A few of these, however, and all the irresolvable nebulæ, afford *bright* lines demonstrative of the vaporous or gaseous state. We are led, therefore, to regard the latter as purely a primitive fire-mist, and the former as a fire-mist already discontinuous by aggregation around local nuclei. The nebula in Draco, besides furnishing bright lines of vaporosity (or gaseity), produces also a feeble *continuous* spectrum, indicative of the first stage of liquefaction. The planetary nebulæ may be regarded as another stage. It may be added, that objects

* Secchi, *Le Soleil*, p. 397.

have been observed which give only continuous spectra, ordinarily characteristic of solid or liquid luminosity. This is true of several dense star-clusters, as well as of a number of resolvable nebulæ. This may result from a solid or liquid state of luminous matter; but it is worthy of suggestion that the continuous spectrum would also result from the presence of a vaporous envelope in such a state of luminosity, temperature, and pressure as to possess an absorptive power exactly equal to its emissive power.

Not only does the spectroscope reveal the physical condition of star-clusters and nebulæ, but it makes known the fact that, while resolvable nebulæ are as rich as the stars in revelations of their chemical constitution, even the purely vaporous nebulæ proclaim the existence within them of at least two familiar substances, hydrogen and nitrogen, with indications, also, of barium.

It will at once appear from what has been thus concisely stated, that the spectroscopic study of cosmical matter beyond the limits of the solar system is strictly complementary to the telescopic study of the bodies belonging to our system. These glimpses of the history of our own earth are carried farther and farther back towards its mysterious beginning, and we recognize, here and there, perpetuated exemplifications of various intermediate stages of terrestrial and indeed of cosmical evolutions. It would, undoubtedly, be hazardous, with our still imperfect knowledge of cosmical states, to attempt to dispose in serial order the various manifestations which seem to represent different stages in the history of matter, and thus pass all the phenomena in a consecutive panoramic view. Still, this result is a desideratum of science, and will ultimately be attained. In the mean time, with due misgivings and reserve, we offer, for the gratification of the reader, the following tentative exhibit of successive stages in the history of world-matter.

I. Nebulous Phases.

1. Gaseity. Matter intensely heated and non-luminous, or only imperfectly luminous, and in a state of chemical dissociation. Perhaps the faint central portions of some of the annular nebulæ (as that in Lyra) exemplify this condition. According to Secchi and Faye, this is the condition of the sun's nucleus.*

2. Normal Nebulosity. Mineral mist caused by the condensation of certain mineral gases, and consisting of minute (probably liquid) incandescent particles, floating in a gaseous medium — most of the elements still retaining their gaseity. Spectrum consists only of one, two, or three bright lines.† Exemplified in *some of the irresolvable nebulæ*.

3. Continuous Fire-mist. Mineral mist increased in quantity, but the mass remains homogeneous and mostly gaseous. Spectrum of bright lines superposed on an extremely faint, continuous spectrum of scarcely appreciable breadth.‡ Exemplified in *certain irresolvable nebulæ*, as H. 4374. A small number of stars also give a similar spectrum, as Gamma Cassiopœiæ and Beta Lyræ. Bright line spectra have also been obtained from two temporary stars.

4. Discontinuous Fire-mist. Segregation and accumulation around local nuclei. Fire-mist or photospheric mat-

* There is no reason to suppose that any large body of matter exists wholly in a state of gaseity, since contact with cold space would immediately produce some peripheral condensation into the state of fire-mist.

† Schellen, *Spectralanalyse*, p. 528. As to the temperature of the nebulæ, while the researches of Huggins, Secchi, and Wüllner seem to indicate that it is extremely high, those of Zöllner, Frankland, and Lockyer — so far as they have been severally interpreted — seem to indicate a comparatively low temperature. It is apparent, moreover, on physical considerations, that a moderate process of condensation would develop, from cool matter, any amount of heat which nebulous or stellar masses may have evinced.

‡ Schellen, Op. Cit., pp. 523, 527, 528.

ter still in small proportion to gaseous. Bright line spectrum superposed on a faint continuous spectrum. Exemplified in *certain resolvable nebulæ*. (Compare nebula in Draco.)

II. STELLAR PHASES.

5. PRIMARY NUCLEAR STAGE. Increasing amount of photospheric matter. Nuclear condensation apparent. Sun-systems approaching the stage of annulation. Bright lines over a continuous spectrum. *Planetary nebulæ*, especially H. 838, H. 464, H. 2098, and H. 2241; and *Nebulous Stars*, as H. 450. A stage a little more advanced is perpetuated in the Saturnian rings; but it is only the *form*, and not the *state*, of the matter which is perpetuated. The spiral and curved nebulæ perhaps exemplify a disturbed or abnormal state of the progress towards annulation.

6. SECONDARY NUCLEAR STAGE. Liquid precipitate increased; nucleation advanced. Temperature and luminosity so diminished that the absorbent capacity of the (still gaseous) atmosphere just equals the emissive power of the luminous nucleus and photosphere. Spectrum continuous. The point of transition from bright line spectra to dark line spectra. Stage observed, probably, in *certain star-clusters*, and *most resolvable nebulæ*.*

7. SIRIAN STAGE. The atmosphere remains of great depth, and exists under a high degree of tension. Absorbent capacity exceeds the emissive. Spectrum of dark lines having an extraordinary breadth.† *White Stars*.

8. ARCTURAN STAGE. The absorbent atmosphere reduced

* The continuous spectrum may, in some cases, be only apparent, the fineness of the lines rendering them invisible with existing instruments.

† The mass of the star, independently of its age, would influence the tension of the absorbent medium, and hence the width of the dark lines. We cannot be certain, therefore, from spectroscopic indications, that this stage precedes the next. Guided by color alone, the white stars should precede the yellow.

in depth and consequent tension to such an extent as to give dark absorptive lines of normal breadth. Spectrum identical with normal spectrum of the sun. *Yellow Stars.*

9. SOLAR STAGE. Photosphere so far reduced in depth by precipitation upon the nucleus, as to be ruptured by the vertical movements of the subjacent umbral or non-luminous zone, and, by condensation, in situations visible from without, of clouds of new photospheric matter temporarily cooler and less luminous than the photosphere, to give rise to the phenomenon of maculation * and incipient variability. Our *Sun* exemplifies this condition.

10. VARIABLE STAGE. Photosphere periodically darkened by the condensation of large amounts of macular matter temporarily cooler and darker than normal photospheric matter. Approaching total liquefaction. *Variable Stars.*

11. LIQUID STAGE. Photospheric matter exhausted, and all absorbent media extremely reduced. A molten globe. Spectrum continuous. Probably some of the *star-clusters* and *resolvable nebulæ.*

12. INCRUSTIVE STAGE. Early periods of incrustation. The light becomes ruddy; incipient darkening. Spectrum of dark lines, but giving the *ensemble* of vaporosity. *Red Stars.*†

13. ERUPTIVE STAGE. The period of constant luminosity passed. Collapses of the crust, at long intervals, give rise to outbursts of glowing matter which rapidly fades

* Secchi and Faye regard the solar spots as openings through the photosphere into the gaseous non-luminous interior — the light *from the opposite side of the sun* not being visible in consequence of the absorbent power of the intervening gas.

† The red stars are ranged here simply in consequence of their color. Judging from their spectra, their position would be between the sixth and seventh stages. Perhaps, however, the dark lines and the indications of vaporosity arise from some temporary or special condition of the enveloping media incident to the incrustive stage.

through the successive phases of luminosity, and disappears from observation. *Temporary Stars.**

III. PLANETARY PHASES.

14. SATURNIAN STAGE. The ring condition.

15. JOVIAN STAGE. A water-mist begins to condense in the peripheral regions, as formerly the fire-mist appeared. It gathers into a vaporous envelope, constituting a true atmosphere or nephelosphere. This precipitates an aqueous rain, the homologue of the molten rain of earlier times, which ultimately finds a resting-place upon the incrusted nucleus. Stage of protophytic, and, later, of protozoic life.

16. TERRESTRIAL STAGE. Aqueous precipitation periodical. Cyclonic movements of the atmosphere, perhaps the homologues of those which cause solar maculations. Culmination of the organic phase.

17. MARTIAL STAGE. Diminished vapors and infrequent rains. Encroaching cold. Decline of the organic phase.

18. LUNAR STAGE. Disappearance of aqueous vapors, and total absorption of the ocean and the air. Extinction of organization. Final refrigeration.

However conjectural some parts of the foregoing arrangement may be, — the precise positions of (6) (7, 8, 9, 10) and (17) being most uncertain, — there is little doubt that its

* The writer is fully aware of the insufficiency of the known data for correlating the various phases of cosmical matter. We need to know much more yet respecting the relations of spectra to temperature, pressure, and molecular arrangement; and also, in view of the analogies drawn from the light in Geislerian tubes, more of the connection between the tension of the electric current and the temperature and density of the gas made luminous by the electric discharge. The reader, nevertheless, who will avoid placing too much stress upon the *details* of the foregoing arrangement, will obtain a correct impression of the great fact of progressive changes in cosmical matter.

general tenor expresses a fact in the aspects of the universe. This we have endeavored to explain and impress. We know enough of the phases of matter in the different provinces of space to feel certain that they represent progressive stages in the natural evolution of matter as such. Whether seen in nebula, star, sun, planet, or satellite, it is a phase in a common history, the earliest periods of which are as truly a part of the history of our world as the achievements of Alfred the Great are a part of the history of communities of American birth.

These views are calculated to produce upon our minds a profound impression of the unity of the universe, both in its spatial extent and its historical development. When we combine with these evidences the indications of the presence of a common ether as the medium of light, and of the supremacy, everywhere, of the universal law of gravitation, we are placed in possession of an overwhelming demonstration of the identity of the government which controls natural events upon our planetary abode, and in departments of space so remote that the mind is utterly prostrated in the attempt to comprehend their distances. Whatever intelligence, power, or goodness may seem to be exemplified in the ordinations of terrestrial affairs are not less certainly illustrated in the phenomena which we trace to the utmost verge of the visible universe, and to the remotest conceivable commencement of material history. The intelligent Power whose supreme control is recognized within the narrow limits of personal experience is ONE through stretches of space and time which, to human faculties, are infinite.

The study of stellar geology leaves us with another reflection. Every phase of matter seen in the universe is a transient one. The various phases sustain demonstrably some sort of historical relation to each other. These states of matter are progressive; we trace them backward towards earlier conditions — towards an earliest condition, beyond which we *know no possibility* of material existence. From that con-

dition to the present is but a finite career, however vast the interval appears, expressed in figures. The history began in time — it does not come down to us from eternity. The material *organism* is therefore originated in time. Now, when we carry our thoughts back to that primal condition indicated, we must necessarily perceive that it existed absolutely unchanged and unprogressive from all eternity, or the *matter itself* which exemplifies it did not exist from eternity. But we have not the slightest scientific ground for assuming that matter existed in a certain condition from all eternity, and only began undergoing its changes a few millions or billions of years ago. For all that we know, — and, indeed, as the *conclusion* from all that we know, — primal matter began its progressive changes on the morning of its existence. As, therefore, the series of changes is demonstrably finite, *the lifetime of matter itself is necessarily finite.* And this conclusion from physical science is in harmony with the intuition of reason which declares that all which exists has been caused by a (necessarily) self-existent and intelligent First Cause, and which perpetually reiterates its judgment, proclaim as we will the "unthinkableness" of self-existence, or of absolute creation from nothing.

Finally, the future life of cosmical organization is as clearly set within limits as its past. There is an ultimate goal towards which all cosmical matter is tending. That goal is not the actual condition of our world, for we see here everything still in a state of change; and the moon exemplifies an ulterior state. It cannot be the Lunar stage, for even there solar light and heat, and terrestrial influences, and universal gravitation, and meteoric matter, and a pervading ether, are all conspiring to avert the condition of absolute repose. The finality lies in the impenetrable darkness of the distant future. What it may be we can only conjecture; but one impending stage of all cosmical matter is positively written upon the face of the moon. Not only must our own planet reach finally that refrigerated and inhospitable condi-

tion, but the sun itself must untimately fade to a darkened planet, and become extinguished in the heavens.

These thoughts summon into our immediate presence the measureless past and the measureless future of material history. They seem almost to open vistas through the eternities, and to endow the human intellect with an existence and a vision exempt from the limitations of the finite, and lift it up towards a sublime apprehension of that Supreme Intelligence whose dwelling-place is eternity.

APRIL, 1872.

ADDENDA.

Page 7. A deductive inference might be introduced respecting the origin of the asteroidal zone. On the nebular theory, a ring must have been detached between Mars and Jupiter. But also, in accordance with the theory, the matter of the ring may have aggregated about *numerous local nuclei which continued a separate existence*, instead of coalescing, as in the case of the other solar rings. The rings of Saturn, according to recent suggestions (see p. 18), would perhaps present, in their granular constitution, only an exaggerated state of the same phenomenon; while binary and multiple stars illustrate another state of aggregation of world-stuff, in which the persistent nuclei are few in number.

It is supposable, also, that the asteroidal ring was originally multiple, or became such, and that each ringlet condensed into a separate planetoid. A susceptibility of indefinite division is noted in the rings of Saturn; and, indeed, the physical conditions concerned in a condensing rotating ring necessitate a tendency to stratification, which might naturally result in a segregation of numerous constituent annuli.

Page 12. In reference to the circumstance that the moon always turns the same side towards the earth, we ought to observe that Herschel conjectured the moons of Jupiter to be similarly circumstanced; and that Delaunay (*Cours élémentaire*, p. 643) thinks this condition was induced by the attraction of the primary planet while the satellite was yet uncondensed.

Page 25. The temperature of a nebula, or other cosmical mass, must be measured by a constant quantity, plus the ratio of its total radiation to its total condensation, through causes not depending on the loss of heat. Condensation through loss of heat would create no tendency to increase the temperature, but condensation through the action of gravity would. The latter cause of condensation could only exist in a mass of matter temporarily out of the condition of molecular equilibrium, and could continue only while it is in the act of adapting its molecular state to the mechanical forces acting upon it. We are unable to state whether these forces vary in different regions and periods, and hence cannot safely assert that every or any nebulous body increases in temperature during any period of its history. It seems more probable that a continuous reduction of temperature is experienced; and that the temperature inherent in the sun at the present time is rather the residuum of the primordial heat than the effect of the condensation of his mass. Neither do the latest researches concede so high a temperature to that body as has been conjectured. The ingenious calculations of Secchi resulted in a solar temperature of at least 10,000,000° Centigrade. Ericsson put it at 4,000,000°; Zöllner, at 400,000° C., and Spörer, at 27,000° C. In a recent discussion in the Academy of Sciences, at Paris, between MM. Faye, Deville, Becquerel, Nizeau, Vualle, and Vicaire, it was generally agreed that the solar temperature could not exceed 10,000° C., while it probably falls short of 3000° C. The temperature which suffices to fuse most rocks is about 3900° C.

10. On Yeast.

A Lecture explaining Protoplasm and the Germ Theory, by PROFESSOR HUXLEY, LL. D., F. R. S., *delivered in the Free Trade Hall, Manchester, November* 3, 1871.

I HAVE selected to-night the particular subject of Yeast for two reasons — or, rather, I should say for three. In the first place, because it is one of the simplest and the most familiar objects with which we are acquainted. In the second place, because the facts and phenomena which I have to describe are so simple that it is possible to put them before you without the help of any of those pictures or diagrams which are needed when matters are more complicated, and which, if I had to refer to them here, would involve the necessity of my turning away from you now and then, and thereby increasing very largely my difficulty (already sufficiently great) in making myself heard. And thirdly, I have chosen this subject because I know of no familiar subject forming part of our every-day knowledge and experience, the examination of which, with a little care, tends to open up such very considerable issues as does this substance — yeast.

In the first place, I should like to call your attention to a fact with which the whole of you are, to begin with, perfectly acquainted; I mean the fact that any liquid containing sugar, any liquid which is formed by pressing out the succulent parts of the fruits of plants, or a mixture of honey and water, if left to itself for a short time, begins to undergo a peculiar change. No matter how clear it might be at starting, yet after a few hours, or at most a few days, if the temperature is high, this liquid begins to be turbid, and by and by bubbles make their appearance in it, and a sort of dirty-looking yellowish foam or scum collects at the surface;

while at the same time, by degrees, a similar kind of matter, which we call the "lees," sinks to the bottom.

The quantity of this dirty-looking stuff, that we call the scum and the lees, goes on increasing until it reaches a certain amount, and then it stops; and by the time it stops, you find the liquid in which this matter has been formed has become altered in its quality. To begin with, it was a mere sweetish substance, having the flavor of whatever might be the plant from which it was expressed, or having merely the taste and the absence of smell of a solution of sugar; but by the time that this change that I have been briefly describing to you is accomplished, the liquid has become completely altered; it has acquired a peculiar smell, and, what is still more remarkable, it has gained the property of intoxicating the person who drinks it. Nothing can be more innocent than a solution of sugar; nothing can be less innocent, if taken in excess, as you all know, than those fermented matters which are produced from sugar. Well, again, if you notice that bubbling, or, as it were, seething of the liquid, which has accompanied the whole of this process, you will find that it is produced by the evolution of little bubbles of air-like substance out of the liquid; and I dare say you all know this air-like substance is not like common air; it is not a substance which a man can breathe with impunity. You often hear of accidents which take place in brewers' vats when men go in carelessly, and get suffocated there without knowing that there was anything evil awaiting them. And if you tried the experiment with this liquid I am telling of while it was fermenting, you would find that any small animal let down into the vessel would be similarly stifled; and you would discover that a light lowered down into it would go out. Well, then, lastly, if after this liquid has been thus altered you expose it to that process which is called distillation, — that is to say, if you put it into a still, and collect the matters which are sent over, — you obtain, when you first heat it, a clear, transparent liquid, which, however, is some-

thing totally different from water: it is much lighter; it has a strong smell, and it has an acrid taste; and it possesses the same intoxicating power as the original liquid, but in a much more intense degree. If you put a light to it, it burns with a bright flame, and it is that substance which we know as spirits of wine.

Now, these facts which I have just put before you — all but the last — have been known from extremely remote antiquity. It is, I hope, one of the best evidences of the antiquity of the human race, that among the earliest records of all kinds of men, you find a time recorded when they got drunk. We may hope that that must have been a very late period in their history. Not only have we the record of what happened to Noah, but if we turn to the traditions of a different people, those forefathers of ours who lived in the high lands of Northern India, we find that they were not less addicted to intoxicating liquids; and I have no doubt that the knowledge of this process extends far beyond the limits of historically recorded time. And it is a very curious thing to observe that all the names we have of this process, and all that belongs to it, are names that have their roots not in our present language, but in those older languages which go back to the times at which this country was peopled. That word "fermentation," for example, which is the title we apply to the whole process, is a Latin term; and a term which is evidently based upon the fact of the effervescence of the liquid. Then the French, who are very fond of calling themselves a Latin race, have a particular word for ferment, which is *levure*. And in the same way we have the word "leaven," those two words having reference to the heaving up, or to the raising of the substance which is fermented. Now, those are words which we get from what I may call the Latin side of our parentage; but if we turn to the Saxon side, there are a number of names connected with this process of fermentation. For example, the Germans call fermentation — and the old Germans did so —

"*gähren;*" and they call anything which is used as a ferment by such names, such as "*gheist*" and "*geest*," and finally in low German, "*ghest;*" and that word, you know, is the word our Saxon forefathers used, and is almost the same as the word which is commonly employed in this country to denote the common ferment of which I have been speaking. So they have another name, the word "*hefe*," which is derived from their verb "*hebèn*," which signifies to raise up; and they have yet a third name, which is also one common in this country (I do not know whether it is common in Lancashire, but it is certainly very common in the Midland counties), the word "*barm*," which is derived from a root which signifies to raise or to bear up. Barm is a something borne up; and thus there is much more real relation than is commonly supposed by those who make puns, between the beer which a man takes down his throat and the bier upon which that process, if carried to excess, generally lands him, for they are both derived from the root signifying bearing up; the one thing is borne upon men's shoulders, and the other is the fermented liquid which was borne up by the fermentation taking place in itself.

Again, I spoke of the produce of fermentation as "spirits of wine." Now, what a very curious phrase that is, if you come to think of it. The old alchemists talked of the finest essence of anything as if it had the same sort of relation to the thing itself as a man's spirit is supposed to have to his body; and so they spoke of this fine essence of the fermented liquid as being the spirit of the liquid. Thus came about that extraordinary ambiguity of language, in virtue of which you apply precisely the same substantive name to the soul of man and to a glass of gin! And then there is still yet one other most curious piece of nomenclature connected with this matter, and that is the word "alcohol" itself, which is now so familiar to everybody. Alcohol originally meant a very fine powder. The women

of the Arabs and other Eastern people are in the habit of tinging their eyebrows with a very fine black powder which is made of antimony, and they call that "kohol;" and the "al" is simply the article put in front of it, so as to say "the kohol." And up to the 17th century in this country the word alkohol was employed to signify any very fine powder: you find in Robert Boyle's works that he uses "alcohol" for a very fine, subtile powder. But, then, this name of anything very fine and very subtile came to be specially connected with this fine and subtile spirit obtained from the fermentation of sugar; and I believe that the first person who fairly fixed it as the proper name of what we now commonly call spirits of wine, was the great French chemist Lavoisier, so comparatively recent is the use of the word alcohol in this specialized sense.

So much by way of general introduction to the subject on which I have to speak to-night. What I have hitherto stated is simply what we may call common knowledge, which everybody may acquaint himself with. And you know that what we call scientific knowledge is not any kind of conjuration, as people sometimes suppose, but it is simply the application of the same principles of common sense that we apply to common knowledge, carried out, if I may so speak, to knowledge which is uncommon. And all that we know now of this substance, yeast, and all the very strange issues to which that knowledge has led us, has simply come out of the inveterate habit — and a very fortunate habit for the human race it is — which scientific men have of not being content until they have routed out all the different chains and connections of apparently simple phenomena, until they have taken them to pieces and understood the conditions upon which they depend. I will try to point out to you now what has happened in consequence of endeavoring to apply this process of "analysis," as we call it, this teasing out of an apparently simple fact into all the little facts of which it is made up, to the ascer-

tained facts relating to the barm or the yeast; secondly, what has come of the attempt to ascertain distinctly what is the nature of the products which are produced by fermentation; then what has come of the attempt to understand the relation between the yeast and the products; and lastly, what very curious side issues — if I may so call them — have branched out in the run of this inquiry, which has now occupied somewhere about two centuries.

The first thing was to make out precisely and clearly what was the nature of this substance, this apparently mere scum and mud that we call yeast. And that was first commenced seriously by a wonderful old Dutchman of the name of Leeuwenhoek, who lived some two hundred years ago, and who was the first person to invent thoroughly trustworthy microscopes of high powers. Now, Leeuwenhoek went to work upon this yeast mud, and by applying to it high powers of the microscope, he discovered that it was no mere mud such as you might at first suppose, but that it was a substance made up of an enormous multitude of minute grains, each of which had just as definite a form as if it were a grain of corn, although it was infinitely smaller, the largest of these not being more than the two-thousandth of an inch in diameter; while, as you know, a grain of corn is a large thing; and the very smallest of these particles were not more than the seven-thousandth of an inch in diameter. Leeuwenhoek saw that this muddy stuff was in reality a liquid, in which there were floating this immense number of definitely shaped particles, all aggregated in heaps and lumps, and some of them separate. That discovery remained, so to speak, dormant for fully a century, and then the question was taken up by a French discoverer, who, paying great attention and having the advantage of better instruments than Leeuwenhoek had, watched these things, and made the astounding discovery that they were bodies which were constantly being reproduced and growing; that when one of these rounded bodies was once formed and had grown to its full size, it

immediately began to give off a little bud from one side, and then that bud grew out until it had attained the full size of the first, and that in this way the yeast particle was undergoing a process of multiplication by budding, just as effectual and just as complete as the process of multiplication of a plant by budding; and thus this Frenchman, Cagniard de la Tour, arrived at the conclusion — very creditable to his sagacity, and which has been confirmed by every observation and reasoning since — that this apparently muddy refuse was neither more nor less than a mass of plants, of minute living plants, growing and multiplying in the sugary fluid in which the yeast is formed. And from that time forth we have known this substance which forms the scum and the lees as the yeast plant; and it has received a scientific name — which I may use without thinking of it, and which I will therefore give you — namely, "Torula." Well, this was a capital discovery. The next thing to do was to make out how this torula was related to other plants. I won't weary you with the whole course of investigation, but I may sum up its results, and they are these — that the torula is a particular kind of a fungus, a particular state, rather, of a fungus or mould. There are many moulds which, under certain conditions, give rise to this torula state, to a substance which is not distinguishable from yeast, and which has the same properties as yeast — that is to say, which is able to decompose sugar in the curious way that we shall consider by and by. So that the yeast plant is a plant belonging to a group of the Fungi, multiplying, and growing, and living, in this very remarkable manner, in the sugary fluid which is, so to speak, the nidus or home of the yeast.

That, in a few words, is as far as investigation — by the help of one's eye and by the help of the microscope — has taken us. But now there is an observer whose methods of observation are more refined than those of men who use their eye, even though it be aided by the microscope; a

man who sees indirectly farther than we can see directly — that is, the chemist; and the chemist took up this question, and his discovery was not less remarkable than that of the microscopist. The chemist discovered that the yeast plant being composed of a sort of bag, like a bladder, inside which is a peculiar soft, semifluid material, — the chemist found that this outer bladder has the same composition as the substance of wood, that material which is called "cellulous," and which consists of the elements carbon, and hydrogen, and oxygen, without any nitrogen. But then he also found (the first person to discover it was an Italian chemist, named Fabroni, in the end of the last century) that this inner matter which was contained in the bag, which constitutes the yeast plant, was a substance containing the elements carbon, and hydrogen, and oxygen, and nitrogen; that it was what Fabroni called a vegeto-animal substance, and that it had the peculiarities of what are commonly called "animal products."

This, again, was an exceedingly remarkable discovery. It lay neglected for a time, until it was subsequently taken up by the great chemists of modern times, and they, with their delicate methods of analysis, have finally decided that, in all essential respects, that substance which forms the chief part of the contents of the yeast plant is identical with the material which forms the chief part of our own muscles, which forms the chief part of our own blood, which forms the chief part of the white of the egg; that, in fact, although this little organism is a plant, and nothing but a plant, yet that its active living parts contain a substance which is called "protein," which is of the same nature as the substance which forms the foundation of every animal organism whatever.

Now we come next to the question of the analysis of the products, of that which is produced during the process of fermentation. So far back as the beginning of the 16th century, in the times of transition between the old alchemy and

the modern chemistry, there was a remarkable man, Van Helmont, a Dutchman, who saw the difference between the air which comes out of a vat where something is fermented and common air. He was the man who invented the term "gas," and he called this kind of gas "*gas silvestre*," — so to speak, gas that is wild and lives in out of the way places, — having in his mind the identity of this particular kind of air with that which is found in some caves and cellars. Then, the gradual process of investigation going on, it was discovered that this substance, then called "fixed air," was a poisonous gas, and it was finally identified with that kind of gas which is obtained by burning charcoal in the air, which is called "carbonic acid." Then the substance alcohol was subjected to examination, and it was found to be a combination of carbon, and hydrogen, and oxygen. Then the sugar which was contained in the fermenting liquid was examined, and that was found to contain the three elements carbon, hydrogen, and oxygen. So that it was clear there were in sugar the fundamental elements which are contained in carbonic acid, and in the alcohol. And then came that great chemist Lavoisier, and he examined into the subject carefully, and possessed with that brilliant thought of his, which happens to be propounded exactly apropos to this matter of fermentation — that no matter is ever lost, but that matter only changes its form and changes its combinations — he endeavored to make out what became of the sugar which was subjected to fermentation. He thought he discovered that the whole weight of the sugar was represented by the weight of the alcohol produced, added to the weight of the carbonic acid produced; that, in other words, supposing this tumbler to represent the sugar, the action of fermentation was as it were the splitting of it, the one half going away in the shape of carbonic acid, and the other half going away in the shape of alcohol. Subsequent inquiry, careful research with the refinements of modern chemistry, have been applied to this problem, and they have

shown that Lavoisier was not quite correct; that what he says is quite true for about 95 per cent. of the sugar, but that the other 5 per cent., or nearly so, is converted into two other things; one of them matter which is called succinic acid, and the other matter which is called glycerine, which you all know now as one of the commonest of household matters. It may be that we have not got to the end of this refined analysis yet, but at any rate, I suppose I may say, — and I speak with some little hesitation for fear my friend Professor Roscoe here may pick me up for trespassing upon his province, — but I believe I may say that now we may account for 99 per cent. at least of the sugar, and that that 99 per cent. is split up into these four things — carbonic acid, alcohol, succinic acid, and glycerine. So that it may be that none of the sugar whatever disappears, and that only its parts, so to speak, are rearranged, and if any of it disappears, certainly it is a very small portion.

Now, these are the facts of the case. There is the fact of the growth of the yeast plant; and there is the fact of the splitting up of the sugar. What relation have these two facts to one another?

For a very long time that was a great matter of dispute. The early French observers, to do them justice, discerned the real state of the case, namely, that there was a very close connection between the actual life of the yeast plant and this operation of the splitting up of the sugar; and that one was in some way or other connected with the other. All investigation subsequently has confirmed this original idea. It has been shown that if you take any measures by which other plants of like kind to the torula would be killed, and by which the yeast plant is killed, then the yeast loses its efficiency. But a capital experiment upon this subject was made by a very distinguished man, Helmholz, who performed an experiment of this kind. He had two vessels, — one of them we will suppose full of yeast, but over the bottom of it, as this might be, was tied a thin film of bladder;

consequently, through that thin film of bladder all the liquid parts of the yeast would go, but the solid parts would be stopped behind; the torula would be stopped, the liquid parts of the yeast would go. And then he took another vessel containing a fermentable solution of sugar, and he put one inside the other; and in this way, you see, the fluid parts of the yeast were able to pass through with the utmost ease into the sugar, but the solid parts could not get through at all. And he judged thus: if the fluid parts are those which excite fermentation, then, inasmuch as these are stopped, the sugar will not ferment; and the sugar did not ferment, showing quite clearly that an immediate contact with the solid, living torula was absolutely necessary to excite this process of splitting up of the sugar. This experiment was quite conclusive as to this particular point, and has had very great fruits in other directions.

Well, then, the yeast plant being essential to the production of fermentation, where does the yeast plant come from? Here, again, was another great problem opened up, for, as I said at starting, you have under ordinary circumstances, in warm weather, merely to expose some fluid containing a solution of sugar, or any form of syrup or vegetable juice, to the air, in order, after a comparatively short time, to see all these phenomena of fermentation. Of course the first obvious suggestion is, that the torula has been generated within the fluid. In fact it seems at first quite absurd to entertain any other conviction; but that belief would most assuredly be an erroneous one.

Towards the beginning of this century, in the vigorous times of the old French wars, there was a Monsieur Appert, who had his attention directed to the preservation of things that ordinarily perish, such as meats and vegetables; and, in fact, he laid the foundation of our modern method of preserving meats; and he found that if he boiled any of these substances and then tied them so as to exclude the air, they would be preserved for any time. He tried these

experiments, particularly with the must of wine and with the wort of beer; and he found that if the wort of beer had been carefully boiled, and was stopped in such a way that the air could not get at it, it would never ferment. What was the reason of this? That, again, became the subject of a long string of experiments, with this ultimate result, that if you take precautions to prevent any solid matters from getting into the must of wine or the wort of beer, under these circumstances, — that is to say, if the fluid has been boiled and placed in a bottle, and if you stuff the neck of the bottle full of cotton wool, which allows the air to go through, and stops anything of a solid character, however fine, — then you may let it be for ten years and it will not ferment. But if you take that plug out, and give the air free access, then, sooner or later, fermentation will set up. And there is no doubt whatever that fermentation is excited only by the presence of some torula or other, and that that torula proceeds, in our present experience, from pre-existing torulæ. These little bodies are excessively light. You can easily imagine what must be the weight of little particles, but slightly heavier than water, and not more than the two thousandth or perhaps seven thousandth of an inch in diameter. They are capable of floating about and dancing like motes in the sunbeam; they are carried about by all sorts of currents of air; the great majority of them perish; but one or two, which may chance to enter into a sugary solution, immediately enter into active life, find there the conditions of their nourishment, increase and multiply, and may give rise to any quantity whatever of this substance yeast. And whatever may be true or not be true about this "spontaneous generation," as it is called, in regard to all other kinds of living things, it is perfectly certain, as regards yeast, that that always owes its origin to this process of impregnation or inoculation, if you like so to call it, from some other living yeast organism; and so far as yeast is concerned, the doctrine of spontaneous generation is absolutely out of court.

And not only that, but the yeast must be alive in order to exert these peculiar properties. If it be crushed, if it be heated so far that its life is destroyed, that peculiar power of fermentation is not excited. Thus we have come to this conclusion, as the result of our inquiry, that the fermentation of sugar, the splitting of the sugar into alcohol and carbonic acid, glycerine, and succinic acid, is the result of nothing but the vital activity of this little fungus, the torula.

And now comes the further exceedingly difficult inquiry — How is it that this plant, the torula, produces this singular operation of the splitting up of the sugar? Fabroni, to whom I referred some time ago, imagined that the effervescence of fermentation was produced in just the same way as the effervescence of a seidlitz powder; that the yeast was a kind of acid, and that the sugar was a combination of carbonic acid and some base to form the alcohol, and that the yeast combined with this substance, and set free the carbonic acid; just as when you add carbonate of soda to acid you turn out the carbonic acid. But of course the discovery of Lavoisier that the carbonic acid and the alcohol taken together are very nearly equal in weight to the sugar, completely upsets this hypothesis. Another view was therefore taken by the French chemist Thénard, and it is still held by a very eminent chemist, M. Pasteur; and their view is this, that the yeast, so to speak, eats a little of the sugar, turns a little of it to its own purposes, and by so doing gives such a shape to the sugar that the rest of it breaks up into carbonic acid and alcohol.

Well, then, there is a third hypothesis, which is maintained by another very distinguished chemist, Liebig, which denies both the other two, and which declares that the particles of the sugar are, as it were, shaken asunder by the forces at work in the yeast plant. Now, I am not going to take you into these refinements of chemical theory; I cannot for a moment pretend to do so; but I may put the case before you by an analogy. Suppose you compare the

sugar to a card house, and suppose you compare the yeast to a child coming near the card house; then Fabroni's hypothesis was that the child took half the cards away; Thénard's and Pasteur's hypothesis is, that the child pulls out the bottom card and thus makes it tumble to pieces; and Liebig's hypothesis is, that the child comes by and shakes the table, and tumbles the house down. I appeal to my friend here (Professor Roscoe) whether that is not a fair statement of the case.

Having thus, as far as I can, discussed the general state of the question, it remains only that I should speak of some of those collateral results which have come in a very remarkable way out of the investigation of yeast. I told you that it was very early observed that the yeast plant consisted of a bag made up of the same material as that which composes wood, and of an interior semifluid mass which contains a substance identical in its composition, in a broad sense, with that which constitutes the flesh of animals. Subsequently, after the structure of the yeast plant had been carefully observed, it was discovered that all plants, high and low, are made up of separate bags, or "cells," as they are called; these bags or cells having the composition of the pure matter of wood; having the same composition, broadly speaking, as the sac of the yeast plant, and having in their interior a more or less fluid substance containing a matter of the same nature as the protein substance of the yeast plant. And therefore this remarkable result came out, that however much a plant may differ from an animal, yet that the essential constituent of the contents of these various cells or sacs of which the plant is made up, the nitrogenous protein matter is the same in the animal as in the plant. And not only was this gradually discovered, but it was found that these semifluid contents of the plant cell had, in many cases, a remarkable power of contractility, quite like that of the substance of animals. And about twenty-four or twenty-five years ago, namely, about the year 1846, to the

best of my recollection, a very eminent German botanist, Hugo Von Mohl, conferred upon this substance which is found in the interior of the plant cell, and which is identical with the matter found in the inside of the yeast cell, and which again contains an animal substance similar to that of which we ourselves are made up, — he conferred upon this that title of "protoplasm," which has brought other people a great deal of trouble since! I beg particularly to say that, because I find many people suppose that I was the inventor of that term, whereas it has been in existence for at least twenty-five years. And then other observers, taking the question up, came to this astonishing conclusion (working from this basis of the yeast), that the differences between animals and plants are not so much in the fundamental substances which compose them, not in the protoplasm, but in the manner in which the cells of which their bodies are built up have become modified. There is a sense in which it is true — and the analogy was pointed out very many years ago by some French botanists and chemists, — there is a sense in which it is true that every plant is substantially an enormous aggregation of bodies similar to yeast cells, each having, to a certain extent, its own independent life. And there is a sense in which it is also perfectly true — although it would be impossible for me to give the statement to you with proper qualifications and limitations on an occasion like this — but there is also a sense in which it is true that every animal body is made up of an aggregation of minute particles of protoplasm, comparable each of them to the individual separate yeast plant. And those who are acquainted with the history of the wonderful revolution which has been worked in our whole conception of these matters in the last thirty years, will bear me out in saying that the first germ of them, to a very great extent, was made to grow and fructify by the study of the yeast plant, which presents us with living matter in almost its simplest condition.

Then there is yet one last and most important bearing of this yeast question. There is one direction probably in which the effects of the careful study of the nature of fermentation will yield results more practically valuable to mankind than any other. Let me recall to your minds the fact which I stated at the beginning of this lecture. Suppose that I had here a solution of pure sugar with a little mineral matters in it; and suppose it were possible for me to take upon the point of a needle one single, solitary yeast cell, measuring no more perhaps than the three thousandth of an inch in diameter — not bigger than one of those little colored specks of matter in my own blood at this moment, the weight of which it would be difficult to express in the fraction of a grain — and put it into this solution. From that single one, if the solution were kept at a fair temperature, in a warm summer's day, there would be generated in the course of a week enough torula to form a scum at the top and to form lees at the bottom, and to change the perfectly tasteless and entirely harmless fluid, syrup, into a solution impregnated with the poisonous gas, carbonic acid, impregnated with the poisonous substance, alcohol; and that in virtue of the changes worked upon the sugar by the vital activity of these infinitesimally small plants. Now you see that this is a case of infection. And from the time that the phenomena of fermentation were first carefully studied, it has constantly been suggested to the minds of thoughtful physicians that there was a something astoundingly similar between the phenomena of the propagation of fermentation by infection and contagion and the phenomena of the propagation of disease by infection and contagion. Out of this suggestion has grown that remarkable theory of many diseases which has been called the "germ theory of disease;" the idea, in fact, that we owe a great many diseases to particles having a certain life of their own, and which are capable of being transmitted from one living being to another, exactly as the yeast plant is capable of being transmitted from one tum-

bler of saccharine substance to another. And that is a perfectly tenable hypothesis, one which in the present state of medicine ought to be absolutely exhausted and shown not to be true, before we take to others which have less analogy in their favor. And there are some diseases, most assuredly, in which it turns out to be correct. There are some forms of what are called malignant carbuncle which have been shown to be actually effected by a sort of fermentation, if I may use the phrase, by a sort of disturbance and destruction of the fluids of the animal body, set up by minute organisms which are the cause of this destruction and of this disturbance; and only recently the study of the phenomena which accompany vaccination has thrown an immense light in this direction, tending to show by experiments of the same general character as that to which I referred as performed by Helmholz, that there is a most astonishing analogy between the contagion of that healing disease and the contagion of destructive diseases. For it has been made out quite clearly, by investigations carried on in France and in this country, that the only part of the vaccine matter which is contagious, which is capable of carrying on its influence in the organism of the child who is vaccinated, is the solid particles, and not the fluid. By experiments of the most ingenious kind, the solid parts have been separated from the fluid parts, and it has then been discovered that you may vaccinate a child as much as you like with the fluid parts, but no effect takes place, though an excessively small portion of the solid particles, the most minute that can be separated, is amply sufficient to give rise to all the phenomena of the cow pock, by a process which we can compare to nothing but the transmission of fermentation from one vessel into another, by the transport to the one of the torula particles which exist in the other. And it has been shown to be true of some of the most destructive diseases which infect animals, such diseases as the sheep pox, such diseases as that most terrible and destructive disorder of horses, glanders, that in

these, also, the active power is the living solid particle, and that the inert part is the fluid. However, do not suppose that I am pushing this analogy too far. I do not mean to say that the active, solid parts in these diseased matters are of the same nature as living yeast plants; but, so far as it goes, there is a most surprising analogy between the two; and the value of the analogy is this — that by following it out we may some time or other come to understand how these diseases are propagated, just as we understand, now, all about fermentation; and that, in this way, some of the greatest scourges which afflict the human race may be, if not prevented, at least largely alleviated.

This is the conclusion of the statements which I wished to put before you. You see we have not been able to have any accessories. If you will come in such numbers to hear a lecture of this kind, all I can say is, that diagrams cannot be made big enough for you, and that it is not possible to show any experiments illustrative of a lecture on such a subject as I have to deal with. Of course my friends the chemists and physicists are very much better off, because they can not only show you experiments, but you can smell them and hear them! But in my case such aids are not attainable, and therefore I have taken a simple subject and have dealt with it in such a way that I hope you all understand it, at least so far as I have been able to put it before you in words; and having once apprehended such of the ideas and simple facts of the case as it was possible to put before you, you can see for yourselves the great and wonderful issues of such an apparently homely subject.

II. The Relations between Matter and Force.

A Lecture by JOHN H. TICE, *read before the Teachers' Association of the Second District, January* 26, 1872; *and also before the Western Academy of Science, at St. Louis, April* 13, 1872.

THE increasing demand for science teaching and for scientific works must be accepted as satisfactory evidence of a growing desire for acquiring a more intimate, extended, and accurate knowledge of the Physical World. Signs so auspicious inspire hope and confidence that the friends of scientific progress will soon be justified to make the joyful announcement, —

> "Night wanes; the vapors, round the mountain curled,
> Melt into morn, and Light awakes the world."

However, we must not be too sanguine, for the time for the rising of the full orb of Science is not yet; yea, the orb itself is not yet fashioned, for it is still a crude mass; and if it were to rise now, its illuminating power would hardly equal that of a farthing rush candle.

Such an expression, however, is depreciative of our present state of knowledge, and should not be made, unless justified by incontestable facts. What, then, are the facts? There is a broad distinction between knowledge and science. Knowledge is a clear and certain perception of that which exists, or of truth and fact. Science is a body of general principles, particular truths, and facts, arranged in systematic order. The object of Science is to make truth self-evident by deduction and demonstration from incontestable facts. Knowledge is twofold: first, the knowing of isolated facts; and second, the knowing of universal truths demonstrated from these facts by science. Taking this view of the matter, how much of Science have we to teach, except the Mathe-

matics? None whatever; though in several departments of Nature there is a more or less advanced stage of gestation of which Science will be born, but the day of delivery is yet indefinite.

The public demand science teaching; and those having the organization, control, and management of our educational machinery, assuming that we have all kinds of science to teach, very laudably endeavor to meet and satisfy the public demand. They very properly recommend teaching the natural sciences; but what do they mean by the natural sciences? They mean botany, zoölogy, mineralogy, geology, astronomy, chemistry, etc. What do they propose to teach in these branches of science? If we examine their syllabus, we find it begins and ends with the observation, notation, and description of the external forms and properties of Matter, not of its phenomena when affected by universal and all-pervading Force. What they mean, instead of being natural science, is more properly natural history. It is not science, but merely the elements out of which science may be constructed. In astronomy and chemistry, to be sure, it rises somewhat higher, but even there passes not beyond the investigation and determination of mechanical laws.

To observe, note, and describe the external appearances, properties, forms, differences, etc., of matter, or of its mechanical behavior under the influence of an invisible, intangible force, is merely the *letter*, not the spirit, of natural science, or, as it is more generally called, Physical Science; and mentally as well as morally, it is true that the letter killeth, but the spirit giveth life. It is because we stop at the vestibule, and never enter the great temple of Nature, that "the people perish for want of knowledge."

These preliminary remarks are made to justify me in wandering so far, as I shall, from the beaten track in discussing my subject, viz., the Relations between Matter and Force. But even before entering upon it, I find another episode necessary to aid in comprehending the discussion. A com-

plete survey of our own planet, and a searching investigation into the nature of its materials, impress us not only with the sense of its immensity as a mass, but astonish us with the number of the forms and varieties of matter of which it is composed. But when we direct our eyes into the unfathomable depths of Space, we see other orbs rolling there a thousand, and some a million, times larger than our own. In an endeavor to bring the vastness of the Physical Universe within our apprehension, we classify these orbs into systems. We then commence by first contemplating the system dominated by the Sun, consisting of eight primary planets, some twenty or more secondary planets, and one hundred and twenty-five known planetoids. These all obey the Sun, being hurled around him in paths called orbits, while the Sun, with his whole retinue, flies with incredible velocity through space. Withdrawing our regard from the solar system, we direct our attention to the so-called fixed stars. There we find similar systems to our own, — some with one central sun; others, more complicated, with two and three, and one instance five suns, circling round each other. Proceeding step by step, we finally attain a conception of our own galaxy. If we now take our stand beside the elder Herschel at the telescope, and look beyond our own galaxy into the depths of space, we see other galaxies scattered like diamond dust, at distances so immense that it takes light — the swiftest thing that is — a hundred millions of years to traverse space between them and us.

If, now, we wish to form an estimate of the amount of matter in the universe, to that of our Earth we add the quantity of matter in Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, in the twenty moons and one hundred and twenty-five planetoids, and finally that in the Sun himself. We now have the aggregate of matter in the solar system. To this amount we add the quantities contained in similar systems dominated each by a fixed star for a sun, and the total is the amount of matter in our galaxy. If this amount be sup-

plemented by the quantities of matter in all the other galaxies, the sum will be the total of matter in the universe. If we now contemplate this total, we find it so vast and immense, that we cannot even apprehend it. One definite idea, however, we have of it; vast as it is, we know that it is finite. It exists in space, and occupies definite dimensions there, but it does not fill space. We, therefore, can fix limits to Matter, but can we fix limits to space? The idea of limits to space is inconceivable, because it is unthinkable. Space, then, which has no limits, and can have none, must be infinite; and Matter, which exists in it, but does not fill it, must be finite.

If we now fix our attention upon matter in any form, or wherever it exists, we find it has a common attribute. Whether as an atom, molecule, planet, or sun, whenever and whatever it may be, it is never without motion. Why does it move, and what gives it motion? Common sense tells us that its motion must be the result of Force; for otherwise an effect could exist without a cause. Looking out into space, we find the motion of celestial bodies uniform. Even our Moon, which some scientists regard as the mere *cadaver* of a planet, and which Stanislaus Munier predicts will ere long come down on us in a shower of stones, still keeps good time; for in twenty-one hundred and fifty years, admitting the eclipse observations of Hipparchus to be perfectly reliable and exact, she has not lost one sixtieth part of a second. La Place made it only one three hundredth part of a second. The motion of celestial bodies must, therefore, be taken as absolutely uniform; and if the motion is uniform, then the force that produces it must not only be uniform, but continuous also. Now, let the heavenly bodies move out into the regions of space wherever they list, they never do, and never can, move where they are not affected by force. If force, then, affects them at all points in space, then force must fill space; and since space is infinite, so must force be, that fills it. Here our inquiry

seems practically to have reached its limit. We are finite, and if force is infinite, what can we know about it? Can the finite comprehend the infinite? Certainly not; but we can know of infinite force just as much and no more than of any other infinitude. And how much is that? Just as much as is manifested to us in the finite. Of that which is infinite or absolute we cannot have, in any case, direct perception, because we are beings of finite powers. But when the absolute assumes the relative, and manifests itself in a finite form, we can not only perceive, but comprehend it. Absolute Force does so manifest itself to us in Matter which is finite; not, however, as the formless infinite, but in the finite forms of light, heat, electricity, magnetism, etc. These are correlated, convertible, and limited forces, and are generally known under the name of the Physical Forces.

It is from this stand-point that we must survey the phenomena of matter; for in the Physical Forces we find the key that unlocks the secrets of the universe, disclosing its laws in all their ramifications. They open a new page of the book of Nature, which every one is able to read and understand by the light they shed upon it — a wonderful book, containing wisdom such as the eye has never seen, nor the ear heard, nor has it entered into the heart of man to conceive.

The different states of matter are only exponents of the amount of force by which matter is affected. There are four states of matter; the solid, the liquid, the aeriform, and the gaseous, or elementary. I propose to demonstrate the problem that each of these forms but expresses the quantity of force necessary to constitute the given state or form. For convenience sake I will call the transmutation of matter from the solid to the gaseous, or any higher state, the ascending, and the reverse process the descending scale. It has been found by experiment, that on the ascending scale every time matter changes its form, an immense amount of heat disappears: likewise, on the descending scale, each

time a change of state takes place, an immense amount of heat appears. It has also been ascertained that the amounts that disappear in one case, and reappear in the other, are equal. This is incontestable evidence of their identity. The first step, then, is to ascertain what becomes of heat when it disappears, and what it is during the interval between its disappearance and reappearance.

The fact of its being heat both when it disappears and reappears, has led to the inference that it continues to be heat, but in disguise, during the interval. Hence Dr. Black, who, more than a century ago, first observed this phenomenon, proposed to call it latent heat, or heat which transcends the perception of the sensibility. The compound term, latent heat, is therefore unfortunate. Heat means that indefinable and indescribable essence that affects matter so as to acquire the property that gives us the sensation we term warm or hot. The term latent heat is, therefore, self-contradictory; either of its components denying the other in all its terms. It is simply absurd, and on its face bears unimpeachable evidence of our ignorance. It is not only a confession of ignorance, but it is unphilosophical and unpardonable in an age in which the persistence of force and the mutual convertibility of the physical forces are accepted dogmas of science. If we understand the full import of these dogmas, they will teach us better. We have said heat disappears when matter changes its form on the ascending scale, and reappears when it returns to its former state on the descending scale. When, therefore, we assert that matter has changed its form, whether by an advance or retrograde movement, if our assertion means anything, it affirms that matter has undergone a change that is cognizable by the senses, or, in other words, it has acquired new properties, by which it is distinguished from states it was in before or may be again. An effect has been produced upon it; and it is inconceivable that an effect can be produced without an expenditure of force. But do not mistake expenditure as

the synonyme of annihilation, and, consequently, that force has been annihilated. Force is as indestructible as matter; when it disappears it merely changes its form, and persists with all its pristine energy. When heat, therefore, disappears in the transformation of matter, it disappears as heat, but survives in some other mode of force. What is that other mode?

The physical forces, like the mythic Proteus, are constantly changing their form. Given any form of force, and all the other modes of force can be produced from it. Light is convertible into heat, heat into electricity, and electricity into magnetism. Again, with magnetism we can produce electricity; with electricity, heat; and with heat, light. They travel in an eternal round, but in all the cycle of changes they never lose the characteristic of force, while at each turn they do that of light, heat, electricity, or magnetism, as the case may be.

It is a familiar fact that heat is constantly undergoing transformation. The so-called phenomenon of thermo-electricity attests this fact. The instant heat appears in any conducting substance, a current of electricity is found to flow away from the heating point, and magnetic polarity is developed at right angles to the current. If heat accumulates, we know the substance becomes luminous with red or white light, according to the intensity of the heat. These familiar phenomena are illustrations of the doctrine of the convertibility, correlation, and persistence of force. The electric current and magnetic polarity in one instance, and the appearance of light in the other, originate from the conversion of heat into these forees; and it has been ascertained that their energy is equivalent to the amount of heat that has disappeared. In all these instances heat disappears, but we see it reappear in some other mode of force.

From this stand-point let us take a survey of the ground passed over, and ascertain, if possible, the direction of our objective point. We have seen that heat disappears when

matter changes its form on the ascending scale. It has been supposed that in this instance heat itself has not changed, but only has become disguised; and, therefore, it has been proposed to call it latent heat. We have seen other instances in which heat had disappeared, but in its stead light, electricity, and magnetism have made their appearance, since it is inconceivable that these forces can originate from nothing; therefore the logical inference is, that they must have originated from the conversion of heat. By experiment it can be shown that these forces can be converted back again into heat; therefore the truth of the inference is established beyond controversy. Since in all these instances the disappearance of heat is the admitted phenomenon, therefore consistency requires that whatever explanation we give for its disappearance in one instance must apply to all instances. But how stands the fact? In one case we assume that it has not actually disappeared, but only taken a mask to disguise itself; while in the other instances we take its disappearance for a reality, and explain its disappearance by its conversion into other modes of force. If the explanation of disguise be correct, then it must apply to all the others, and logically the conclusion must follow that light, electricity, and magnetism are latent heat also. The final result will be, that all other terms expressing physical energy will disappear from the vocabulary of science, and nothing will remain except heat and latent heat. It is evident that this would leave us less definite ideas of the physical forces, and consequently of the physical world, than we now possess. Instead of being a step forward, it would be an immense stride backward. But this would not end the matter. The reason would be immediately demanded for assigning this superiority over the other physical forces to heat. The sun is the source of energy, not only to the earth, but to the whole solar system. Now, what is the form of energy dispensed by the sun? It is not heat, but light. That heat comes from the sun directly as heat, is one of the most serious errors

of science. No, it does not come so. Energy comes to the earth, and to all matter distributed in space, in the form of light alone; but the manner of its coming I cannot discuss now. What becomes of light when it strikes matter? A part of it (changed, however, into polarized light) is reflected. But what becomes of that which is not reflected? Science, or rather nescience, offers the explanation that it is absorbed. This is an *ignotum per ignotius:* explaining what is unknown by that which is more unknown. Light is an indestructible essence. If it is absorbed, then, though it no longer exists in the form of light, it must still exist in some form of force. What is that form? Let science answer if it can. No; the fiction of the absorption of light was invented before the convertibility, and consequently persistence, of force were discovered; and its retention, long after its fallacy is self-evident, only serves to illustrate how seriously the dead past encumbers the living present. The solution of the enigma is, that matter converts the light emanating from the sun into heat, electricity, and magnetism; the sun thus becomes the great vivifier of nature.

But see what strange facts have come to light. The only mode of energy that comes from a source extraneous to the earth is light. Its transformation into heat, electricity, and magnetism takes place after its arrival here, and in the substance of the earth. It disappears as light, but reappears in the forms of the other forces. Shall we, therefore, call the other forces latent light? We could with far more propriety, than we can, from the disappearance of heat, call any of them latent heat. It is now sufficiently clear that latent heat is an unphilosophical and absurd term. But it has been proposed to make a genus of this absurdity. It has been ascertained that the measurable quantities of heat disappearing at the critical points where matter changes its form, are various; therefore it has been proposed to make four species of latent heat; namely, "of solidity, of liquidity, of vaporization, and of dissociation." What a humiliating spectacle! An ab-

surdity for a genus; and four species of absurdities to constitute the genus! In all seriousness, is there no way to escape this self-stultification? Let us see.

As water is the most familiar form of matter, I will take it for illustration. When it is a solid, we call it ice; when a liquid, water; when aeriform, vapor or steam; and when in its ultimate and homogeneous elements, — hydrogen and oxygen, — gas. As a solid it can exist at any degree of temperature below, but not above, 32 degrees of Fahrenheit; as a liquid, only between 32 degrees and 212 degrees; as a vapor, only between 212 degrees and 5072 degrees; and as hydrogen and oxygen gas, at any degree of temperature above 5072. It is thus seen that the liquid and aeriform states can exist only within prescribed limits on both the ascending and descending scales; that the solid state has a limit only on the ascending, and the elementary only on the descending scale.

The specific amount of force that molecules of ice have, is not known. But this much is known: they cannot acquire an amount of force greater than will raise their temperature above 32 degrees of Fahrenheit. Though their constituting force is an unknown quantity, their maximum is this unknown quantity increased by an amount of heat sufficient to raise their temperature to 32 degrees. On the other hand, in their atomic state, that is, as hydrogen and oxygen gas, we do not know their *maximum* of force, but their *minimum;* that is, they cannot lose more heat than will sink their temperature lower than 5072 degrees. Do not, however, understand me as asserting that oxygen and hydrogen gas cannot exist together, in a state of mechanical mixture, at a lower temperature, for they can so exist at any temperature, and for an indefinite period; but I mean that at any temperature above 5072 degrees they *will not combine;* because at that degree of heat and above it, all chemical affinity between them is destroyed; or, rather, there is no attraction, but repulsion.

I may appropriately here mention a wonderful phenomenon, catalysis, which has not as yet received a satisfactory explanation. If a glass jar is filled with hydrogen and oxygen gas, in the exact proportions in which they combine to form water, — that is, one ninth by weight of hydrogen and eight ninths of oxygen, — they will remain without combining indefinitely, if the jar is kept in the dark. But if a third body, a piece of platinum for instance, be introduced, they instantly combine, and with so much violence as to shatter the jar. An electric spark sent through the jar has a similar effect.

Returning to the subject under investigation: let us more closely examine its extraordinary facts. It has been found by experiment, that a pound weight falling 772 feet, or, which is the same thing, 772 pounds falling one foot, exert a force equal to raising the temperature of one pound of water through one degree of Fahrenheit. Consequently the quantity of heat that will raise the temperature of one pound of water one degree of Fahrenheit, is equivalent to a mechanical power that will raise one pound weight 772 feet, or 772 pounds one foot. Heat sufficient to raise the temperature of one pound of water one degree, is called a thermal unit, or more commonly unit of heat. Whenever, therefore, we know the units of heat expended to produce any effect, we can calculate the mechanical power exerted. Conversely, if in any process we can determine the units of heat developed, we can ascertain the mechanical power developed by that process. From these *data* we can make accurate calculations of the wonderful and tremendous energy exerted by the physical forces. At present, however, I must limit myself to the problem of demonstrating the immense amount of force that is locked up, or liberated, when matter changes its form — locked up when the change is on the ascending scale, and liberated when on the descending.

If we take a pound of ice at 32 degrees of Fahrenheit, and place it in a vessel, and pour over it a pound of water heated

to 174.65 degrees, the pound of hot water in a short time will melt the pound of ice. When it has done so, if we test the water by a thermometer, we find that the whole mixture now has the same temperature, namely, 32 degrees, that the ice had at the beginning of the experiment. The pound of ice, in liquefying, therefore, has gained nothing in temperature; but the pound of water has lost the difference between 174.65 degrees and 32 degrees, which is 142.65 degrees. Scientists offer as an explanation of this phenomenon, that the 142.65 degrees of heat have become latent. This explanation might be suffered to pass unchallenged, if the form of matter remained unchanged; but it has undergone an entire transformation. It was a solid, but now it is a liquid. What has affected this transformation? Unquestionably the force that was expended. It accumulated more force than was compatible with its continuance in the solid state. Force, therefore, broke up one molecular arrangement and made another. In the instance before us heat did this, and in the effort was expended. But we have already seen that force is indestructible; therefore, when we speak of its expenditure, we mean it does its work, whatever it may be, at the expense of its *form*, but not of its *being*. Force may cease to exist as heat, but it survives as light or electricity. In the case now under consideration, in round numbers 143 degrees have been expended, but that on which it has been expended has not gained one iota in temperature. Has it, then, been expended without producing any effect? Our eyes tell us that a very manifest effect has been produced; and a change so great has occurred as to be palpable to all our senses. They all tell us there is a wide difference between ice and water. They bear concurrent testimony that matter has changed, but they cannot inform us what wrought the transformation; and why? Because force is an immaterial, or, if you choose, a spiritual essence, and, therefore, not cognizable by the sensibility. All we know about it, or ever can know about it, comes

through manifestations by matter. What do we know of light, except that it makes matter visible? and of the laws and properties of light, except what matter reveals to us? Abstract matter and the conception of light becomes an impossibility. What is true of light is also true of heat, electricity, and magnetism. We know them only as affections of matter, producing changes of form and aspect, and causing the appearance of secondary properties in it; but without matter they would remain forever unknown to us. Observation has disclosed the fact that all the Physical Forces are mutually convertible, but with every conversion of force new properties arise in matter.

Here a clew is furnished us to pursue successfully our inquiry into the nature and office of the force into which heat is converted when it effects a change of form in matter — a clew for obtaining a definite and clear conception of its character, and for determining its reality and function. Let us repeat our *data*. All the physical forces, by which are meant light, heat, electricity, and magnetism, manifest themselves as affections of matter; that is, they develop secondary properties in matter, by which they become cognizable to us. Though immaterial essences, yet we are just as certain of their reality as though they were direct objects of perception. In what manner do we obtain this definite and certain knowledge of them? Simply by observing that when matter is affected by them, such secondary properties appear in it as in some way to affect our sensibility; so that we are enabled to declare that this matter is affected by light, that by heat; one by electricity, and another by magnetism.

In the case under examination, we find that matter is no longer what it was: it has changed state. It was a solid, but now it is a liquid. So great is the difference between its past and present state, that all our senses recognize the change. It cannot have changed without some cause, and what cause but a physical force? Then that specific force

expended itself; and if it expended itself it survives in some other specific form, for this is a universal law of force, and a corollary from the postulate of its persistence. Now, what is the name of that specific force, and what its function? Science has no name for it, and as for its function, it could not discover it until it had discovered the force. It is true it has offered the nugatory term latent heat, to account for the phenomenon of the disappearance of heat; but it has not risen so high as to conceive it to be a force, or, much less, to discover its function. In the application of the term, it was not so much the intention to express energy, as impotency; or at most to express *potential*, not *actual* energy. What, then, shall we name this force? I cannot conceive a better, nor a more appropriate name for it than that expressing the function it performs in the economy of Nature. Now, what is its function? Suppose we fix our attention on some particular but limited quantity of matter. We find it a solid, but we find it not devoid of force; for it has tenacity, resilience, resistance, and other properties that indicate the presence of force. We find it in the so-called rigid state in which its molecules have scarcely any freedom of motion amongst themselves. We, however, concede it force, and affirm that it has only force enough to constitute it a solid. There is, however, a higher state, the liquid, in which the molecules have greater freedom of motion. But to attain a state of greater freedom amongst its molecules, the universal, scientific and unscientific, judgment is, and always has been, that it must acquire sufficient force to constitute this state of greater freedom of motion. Ever since ice, metals, or anything else have been melted by mankind, the fact of this thing has been known, although not its philosophy.

But, following the progress of matter upward, from the liquid to the aeriform, and from the aeriform to the gaseous state, we find, at each step upward, the molecules, and finally the atoms, have greater freedom of motion amongst themselves than they had in the preceding state, and we find

this greater freedom is owing to the greater quantity of force by which they are affected. It is therefore evident that to constitute the different forms of matter, various but definite quantities of force must be present, and that the amount of force so present determines the form that the matter will assume. In other words, the varying degrees of intensity the force has, constitute the form of matter. The function of the force, therefore, is to *constitute* the states of matter; and I propose to call it the Constitutive Force; or, coining a new word, Constitutism.

The mechanical equivalent of constitutism in the solid state "is past finding out." Even did we know the absolute zero point, all we could then affirm of the constitutism of solidity would be, that it is the residuum of energy, after subtracting the temperature of absolute zero. But the discussion of absolute zero would require a lecture of itself, and would not be practicable at the commencement of a discussion of Natural Energetics.

From what has already been said, the difference in energy between the constitutism of solidity and that of liquidity can be accurately known. In respect to water, we have seen that a unit of heat is that quantity which will raise the temperature of one pound of water through one degree of the scale of Fahrenheit's thermometer; and the mechanical power of this one unit is equal to the force that will raise 772 pounds one foot high. We have seen that 143 units of heat are expended to change a pound of ice into water; therefore, in the transformation of one pound of ice into water, a mechanical force is expended equal to raising 143 times 772 pounds — equal to 110,396 pounds, or more than 55 tons — one foot high. This, therefore, is the difference in energy between the constitutism of solidity and that of liquidity. If we now consider that this is the exponent of the power necessary to change a pound of ice into water, and then consider the millions of tons of ice liquefied every spring and summer by the sun, we catch a faint glimpse of the

tremendous energy exerted by Nature in carrying on the economy of the universe. But vast and almost incredible as the result appears, it is insignificant when compared with what would be necessary to affect the transformation of all this water into the aeriform and thence into the gaseous state.

However, no two substances are raised through the same scale of temperature by the application of the same quantity of heat. For instance, it takes thirty-three times as many units of heat to raise the temperature of water through one degree as it does that of mercury, and eleven times as many as it does that of iron. The relations of different bodies to heat are in proportion to their atomic weights. The lighter the atoms of which a body is composed, the greater is its capacity for heat. In water, on Fahrenheit's scale, there are 180 degrees between the freezing and the boiling point. But the quantity of heat that will raise one pound of water 180 degrees, will raise one pound of mercury 33 times 180 degrees, which are 5940 degrees; or it will raise 33 pounds of mercury 180 degrees. But 212 degrees is the limit of the capacity of water to take up heat; therefore, to accommodate itself to a greater quantity of force than is expressed by 212 units of heat, it has to change its form. When, however, it changes form, heat, that compels it to make the change, also changes form with it, and, conseqnently, disappears. It has been ascertained that, in transforming a pound of water into a pound of vapor, 965 units of heat are expended. This, then, is the mechanical equivalent of the energy necessary to be present to constitute a pound of aqueous vapor. Since one unit of heat is a power equal to raising 772 pounds one foot, therefore the mechanical equivalent of the constitutism of one pound of aqueous vapor is 965 times 772 foot pounds, equal to 744,980 foot pounds; or it possesses energy enough to lift 372½ tons one foot high.

Steam has a capacity to take up 5072 degrees of heat, but a crisis comes on if a greater quantity is applied to it.

To meet this crisis, and to accommodate the force assailing it, another and a final change takes place; the molecules of steam separate into their atomic elements; that is, into oxygen and hydrogen gas. Heat, again, is the agent that compels this change; but in the act it is itself changed, and disappears as heat. By experiment it has been ascertained that when the elements of steam dissociate, that is, separate into two classes of homogeneous atoms, 8000 degrees of heat disappear. The constitutism of eight ninths of a pound of oxygen and one ninth of a pound of hydrogen is therefore equivalent to a power that will lift 8000 times 772 foot pounds, that is, 6,176,000 foot pounds; or it has energy enough to lift 3088 tons one foot high.

We have had under consideration a single pound of matter, namely, water; and we have seen that on the ascending scale, at the critical points where it changed form, an immense amount of mechanical power disappeared. We have calculated and ascertained the equivalence of *this* energy; but we have not calculated the energy expended at points intervening the critical points. Consequently we have not ascertained the total of energy necessarily expended in changing a pound of ice into a pound of gas. If we calculate the energy of the 180 units of heat between the freezing and the boiling point, and that of the 5072 between that of vaporization and gasification, and add their amounts to the sum of those at the critical points, we find the total energy expended in changing a pound of ice into gas equals a power capable of lifting 7533 tons one foot high.

But, according to the doctrine of the persistence of force, this amount of energy has not been lost; and there is not, therefore, this amount less of energy in the world; but it is only stored or locked up in the great storehouse of Nature; and consequently, under proper conditions, this energy must reappear in all its pristine vigor. Experiment has demonstrated that, by cooling, and by the evolution of heat at the critical points, namely, where the gases combine to form

vapor, the vapor condenses into water, and where the water freezes, the precise quantity of heat is evolved that disappeared at those points. Consequently the mechanical power developed on the descending scale is equal to that expended on the ascending.

From these statements it is evident that if we could command a sufficient supply of oxygen and hydrogen gases, and adapt contrivances so as to make them available for mechanical power, we should have under our control an agent whose energy surpassed all others as a heating, smelting, or motive power. The cheap production of these gases is a question for which the future must furnish a solution; for when it is solved, the question of the substitute for coal and wood, when these are exhausted, is solved also. It is thus seen how the most abstruse problems in physical science connect themselves with practical purposes and the every-day affairs of life.

Our discussion has disclosed how the revelations of science expose errors in our preconceived opinions, and how they enable us to correct our judgments. The general opinion is, that but few substances are explosive, such as powder, gun-cotton, nitro-glycerine, dynamite, dualine, etc. If the immense energy necessary to convert a pound of ice into gas were applied so as to produce this transformation instantly, water would be regarded as one of the most powerful explosives in existence. A pound of water occupies 22¾ cubic inches: the gases necessary to constitute a pound of water occupy 44,832 cubic inches. Then, according to the supposition, there would be an instant expansion of one cubic inch into 2000 cubic inches, and, as we have seen, with a force equal to lifting 7533 tons one foot high. But this is not a mere supposition; it is a reality, and is what actually takes place in boiler explosions. Is it, then, a wonder that we look with awe, terror, and dismay at the energy displayed?

In earthquakes and volcanic action (both of which I re-

gard as electric phenomena) immense amounts of hydrogen and oxygen are frequently emitted. Whence these gases?

About forty years ago Beccaria made an experiment, which answers not only the question as to the origin of the gases, but also indicates the cause of earthquakes and volcanic action. He inserted a drop of water between the termini of two wires in the centre of a glass ball two inches in diameter. On sending an electric shock through the wires, the ball exploded with great violence, and was dispersed into dust.

The disappearance of heat when ice melts, and its reappearance when water freezes, explain certain physical phenomena which every one must have observed. In autumn we generally have fine weather, and severe cold does not set in until after the middle of December. But winter, for months, often dallies in the lap of spring. Now, the sun has the same altitude, and must therefore exert the same power, in January as in November, in February as in October, in March as in September, and in April as in August. These months should therefore have the same temperature, each to each; but we know they are very dissimilar in that respect. There must be a physical cause for this dissimilarity. What is that cause? Our discussion has elucidated it. In autumn immense amounts of water within the Arctic Ocean, Hudson's Bay, and thousands of lakes, freeze. Consequently an enormous amount of heat is set free, which re-enforces the energy of the declining sun. But in spring the reverse process takes place. The ice has to be transformed into water again, and a great part of the energy dispensed by the sun is withdrawn and locked up. Hence it is that not until after the sun has touched the northern tropic, and is making his way back towards the equator, can he make his full power felt.

I have demonstrated that there is a constitutive force, and that its function is to constitute the various states or forms of matter. Has it no other function?

An interminable controversy has been raging for centuries as to the condition of space, whether it be full or empty. Some have fiercely contended that it is a plenum; others as dogmatically have asserted it be a vacuum. Can constitutism throw any light upon this vexed question? Let us see.

The way to decide this question is to determine whether there ever was, or ever can be, a vacuum? Men have in various ways endeavored to create vacuums. That under the receiver of the air pump, it is admitted, is far from being so. But it is said the Torricellian vacuum of the barometer would be perfect, if it were not for the presence of an infinitesimally small quantity of mercurial vapor. Suppose, then, the vapor of mercury can be removed; would it then be a vacuum? There would then be no matter present, but would there be nothing else present? I have demonstrated that force is infinite. If man can create a vacuum in which force is not, then force is not infinite, for here is a place where it is not, and it would therefore be limited by this vacuum. The concession of a vacuum is, then, inadmissible, if by a vacuum is to be understood the absence of force. But if it be conceded that force fills it, then it is not a *vacuum*, but a plenum. Can, then, the presence of force be demonstrated? If the barometer is shaken so that the mercury oscillates, flashes of light are emitted every time the mercury ascends the tube and shortens the so-called vacuum. If nothing is there, then this light springs from nothing, and a creation has taken place. Again, if a thermometer be placed under the receiver of an air pump, and the air exhausted, the thermometer not only falls, but falls in proportion to the exhaustion of the receiver. At every stroke of the piston, the air becoming rarer, the thermometer indicates the disappearance of heat. What becomes of the heat? This can only be answered by stating what takes place in the receiver. At every stroke of the handle of the pump, the matter in the receiver becomes more attenuated, or rather the distances between the atoms are increased. What fills up the enlarged interatomic

spaces? The phenomenon of the disappearance of heat answers that question. Heat becomes transformed into constitutism, and thus fills the interatomic spaces. Consequently, in a philosophical sense there can be no vacuum. What places this conclusion beyond controversy is the fact that an *experimentum crucis* shows that the same quantity of heat that disappeared under exhaustion, reappears when the receiver is refilled. Constitutism, therefore, bears testimony not only that space is a plenum, but it also indicates what constitutes it so. To scientists it is not necessary to state the logical consequences of these deductions and facts; namely, they must work a great change in the opinions and theories of physical science. They are fatal to the undulatory theory of light, since they explode the hypothetical ether upon which it rests; they indicate the direction in which absolute zero is to be sought and found, and its immense function ascertained; they make the attributes of attraction and repulsion in matter clear, comprehensible, and intelligible; they demonstrate that motion is not one of the physical forces; and they enlarge our views of the constitution of solar systems, galaxies, in fine, of the whole universe. But I cannot pursue their logical consequences at present to a demonstration.

In making this imperfect sketch of a small plat in the domain of nature, a wide field, immense in proportions and resplendent with light, suddenly bursts into view; but we have to check ourselves, and resist the temptation to enter and explore it for the present. Each additional year shows an increasing desire for science teaching; and it is well that educators are agitating the problem how to meet the demand. For the solution of the problem it is well that they are looking in the direction of the natural sciences. Their war upon the dead matter in text-books is also opportune; it will result in making our children learn less from books and more from nature. Teach them first to read the greatest and best of all books, the volume of

nature; for it is God's book. It contains more wisdom on one page than is contained in all the pages ever written by man, and more food for thought than all the libraries in the world. But teach them so that when they can read it, they cannot alone read its facts, but its laws; not alone the *body*, but the *spirit* of nature.

22

12. The Stone Age: Past and Present.

THE Stone Age is that period in the history of mankind during which stone is habitually used as a material for weapons and tools. Antiquaries find it convenient to make the Stone Age cease whenever metal implements come into common use, and the Bronze Age, or the Iron Age, supervenes. But the last traces of a Stone Age are hardly known to disappear anywhere, in spite of the general use of metals; and in studying this phase of the world's history for itself, it may be considered as still existing, not only among savages who have not fairly come to the use of iron, but even among civilized nations. Wherever the use of stone instruments, as they were used in the Stone Age proper, is to be found, there the Stone Age has not entirely passed away. The stone hammers with which tinkers might be found at work till lately in remote districts in Ireland, the huge stone mallets with wooden handles which are still used in Iceland for driving posts and other heavy hammering, and the lancets of obsidian with which the Indians of Mexico still bleed themselves, as their fathers used to do before the Spanish Conquest, are stone implements which have survived for centuries the general introduction of iron.

Mere natural stones, picked up and used without any artificial shaping at all, are implements of a very low order. Such natural tools are often found in use, being for the most part slabs, water-worn pebbles, and other stones suited for hammers and anvils; and their employment is no necessary proof of a very low state of culture. Among the lower races, Dr. Milligan gives a good instance of their use, in describing the shell-mounds left by the natives on the shores of Van Diemen's Land. In places where the shells

found are univalves, round stones of different sizes are met with; one, the larger, on which they broke the shells; the other, and smaller, having served as the hammer to break them with. But where the refuse-mounds consist of oysters, mussels, cockles, and other bivalves, there flint-knives, used to open them with, are generally found. Sir George Grey's description of the sites of native encampments, so frequently met with in Australia, will serve as another example. The remains of such an encampment consist of a circle of large flat stones arranged round the place where the fire has been; on each of the flat stones a smaller stone for breaking shell-fish; besides each pair of stones a large shell used for a cup, and, scattered all around, broken shells and bones of kangaroos.

Nor are cases hard to find of the use of these very low representatives of the Stone Age carried up into higher levels of civilization. Thus the tribes of Central and Southern Africa, though often skilful in smiths' work, have not come thoroughly to the use of the iron hammer and anvil. Travellers describe them as forging their weapons and tools with a stone of handy shape and size, on a lump of rock which serves as an anvil; while sometimes an iron hammer is used to give the last finish. The quantities of smooth rolled pebbles found in our ancient English hill-forts were probably collected for sling-stones; but larger pebbles, very likely used as cracking-stones, are found in early European graves. At the present day, the inhabitants of Heligoland and Rügen not only turn to account the natural net-sinkers formed by chalk-flints, out of which the remains of a sponge, or such thing, has been washed, leaving a convenient hole through the flint to tie it by, but they have been known to turn such a perforated flint into a hammer, by fixing a handle in the hole. And lastly, the women who shell almonds in the south of France still use a smooth water-worn pebble (*couède*, *couédou*), as their implement for breaking the shells.

The distinction between natural and artificial implements is of no practical value in estimating the state of culture of a Stone Age tribe. A natural chip or fragment of stone may have been now and then used as an edged or pointed tool; but we have not the least knowledge of any tribe too low habitually to shape such instruments for themselves. There is, however, a well-marked line of distinction in the Stone Age which divides it into a lower and a higher section. We have no historical knowledge of any tribe who have used stone instruments, and have not been in the habit of grinding or polishing some of them. But there are remains which clearly prove the existence of such tribes, and thus the Stone Age falls into two divisions, the Unground Stone Age and the Ground Stone Age.

To the former and ruder of these two classes belong the instruments of the Drift or Quaternary deposits, and of the early bone caves, and, in great part at least, those of the Scandinavian shell-heaps, or kjökkenmöddings. Even should a few ground instruments prove to belong to these deposits, the case would not be much altered, for the finding of hundreds of unground implements unmixed with ground ones would still show a vast predominance of chipping over grinding, which would justify their being classed in an Unground Stone Age, quite distinct from the Ground Stone Age in which modern tribes have been found living.

The rude flint implements found in the drift gravels of the Quaternary (*i. e.* Post-Tertiary) series of strata, belong to the earliest known productions of human art. Since the long unappreciated labors of M. Boucher de Perthes showed the historical importance of these relics, the date of the first appearance of man on the earth has been much debated. I have no purpose of attempting to discuss the collection of geological and antiquarian fact and argument brought forward in Sir Charles Lyell's "Antiquity of Man," not only with reference to the men of the drift period, but to those of the bone caves, and of the early shell-heaps and

peat-bogs. But it may be remarked that geological evidence, though capable of showing the lapse of vast periods of time, has scarcely admitted of these periods being brought into definite chronological terms; yet it is only geological evidence that has given any basis for determining the absolute date at which the makers of the drift implements lived in France and England. In an elaborate paper published in 1864, Mr. Prestwich infers, from the time it must have taken to excavate the river-valleys, even under conditions much more favorable than now to such action, and to bore into the underlying strata the deep pipes or funnels now found lined with sand and gravel, that a very long period must have elapsed since the implement-bearing beds began to be laid down. But his opinion is against extreme estimates, and favors the view that the now undoubted contemporaneity of man with the mammoth, the *Rhinoceros tichorhinus*, etc., is rather to be accounted for by considering that the great animals continued to live to a later period than had been supposed, than that the age of man on earth is to be stretched to fit with an enormous hypothetical date. Mr. Prestwich thus sums up his view of the subject: "That we must greatly extend our present chronology with respect to the first existence of man appears inevitable; but that we should count by hundreds of thousands of years is, I am convinced, in the present state of the inquiry, unsafe and premature."

A set of characteristic drift implements would consist of certain tapering instruments like huge lance-heads, shaped, edged, and pointed, by taking off a large number of facets, in a way which shows a good deal of skill and feeling for symmetry; smaller leaf-shaped instruments; flints partly shaped and edged, but with one end left unwrought, evidently for holding in the hand; scrapers with curvilinear edges; rude flake-knives, etc. Taken as a whole, such a set of types would be very unlike, for instance, to a set of chipped instruments belonging to the comparatively late

period of the cromlechs in France and England. But a comparison of particular types with what is found elsewhere, breaks down any imaginary line of severance between the men of the Drift and the rest of the human species. The flake-knives are very rude, but they are like what are found elsewhere, and there is no break in the series which ends in the beautiful specimens from Mexico and Scandinavia. The Tasmanians sometimes used for cutting or notching wood a very rude instrument. Eye-witnesses describe how they would pick up a suitable flat stone, knock off chips from one side, partly or all round the edge, and use it without more ado; and there is a specimen corresponding exactly to this description in the Taunton Museum. An implement found in the Drift near Clermont would seem to be much like this. The Drift tools with a chipped curvilinear edge at one end, which were probably used for dressing leather and other scraping, are a good deal like specimens from America. The leaf-shaped instruments of the Drift differ principally from those of the Scandinavian shell-heaps, and of America, in being made less neatly and by chipping off larger flakes; and there are leaf-shaped instruments which were used by the Mound-Builders of North America, perhaps for fixing as teeth in a war-club in Mexican fashion, which differ rather in finish than in shape from the Drift specimens. Even the most special type of the Drift, namely, the pointed tapering implement like a great spear-head, differs from some American implements only in being much rougher and heavier. There have been found in Asia stone implements resembling most closely the best marked of the Drift types. Mr. J. E. Taylor, British Consul at Basrah, obtained some years ago from the sun-dried brick mound of Abu Shahrein, in Southern Babylonia, two taper-pointed instruments of chipped flint, which, to judge from a cast of one of them, would be passed without hesitation as Drift implements. As to the date to which these remarkable specimens belong, there is no sufficient evidence.

A stone instrument, found in a cave at Bethlehem, does not differ specifically from the Drift type. To these must be added the quartzite implements of Drift type from the laterite deposits of Southern India, described by Mr. R. Bruce Foote.

With the Unground Stone Age of the Drift, that of the Bone Caves is intimately connected. In the Drift, geological evidence shows that a long period of time must have been required for the accumulation of the beds which overlie the flint implements, for the cutting out of the valleys to their present state, and so on, since the time when the makers of these rude tools and weapons inhabited France and England in company with the *Rhinoceros tichorhinus*, the mammoth, and other great animals now extinct. In the Bone Caves this natural calendar of strata accumulated and removed is absent, but their animal remains border on the fauna of the Drift, and the Drift series of stone implements passes into the Cave series, so that the men of the Drift may very well be the makers of some Cave implements contemporaneous with the great quaternary mammals.

The explorations made with such eminent skill and success in the caverns of Périgord by M. Lartet and Mr. Christy, bring into view a wonderfully distinct picture of rude tribes inhabiting the south of France, at a remote period characterized by a fauna strangely different from that at present belonging to the district, the reindeer, the aurochs, the chamois, and so forth. They seem to have been hunters and fishers, having no domesticated animals, not even the dog; but they made themselves rude ornaments, they sewed with needles with eyes, and they decorated their works in bone, not only with hatched and waved patterns, but with carvings of animals done with considerable skill and taste. Yet their stone implements were very rude, to a great extent belonging to absolute Drift types, and destitute of grinding, with one curious set of exceptions, certain granite pebbles with a smooth hollowed cavity, some of which resemble

stones used by the Australians for grinding something in, perhaps paint to adorn themselves with. It is very curious to find these French tribes going so far in the art of shaping tools by grinding, and yet, so far as we know, never catching the idea of grinding a celt.

The stone implements of the Scandinavian shell-heaps are a good deal like those of the Drift and the Caves, as regards their flint-flakes and leaf-shaped instruments, but they are characterized by the frequent occurrence of a kind of celt which is not a Drift type. It is rudely shaped from the flint, the natural fracture of which gives it a curved form, which may be roughly compared to that of a man's front tooth, if it tapered from root to edge. Here, also, the Unground Stone Age prevails, though a very few specimens of higher types have been found. I may quote Mr. Christy's opinion that the thousands of characteristic implements are to be taken as the standard of what was made and used, while, as has very often happened in old deposits lying in accessible situations, a few things may have got in in comparatively modern times.

Besides the want of grinding, the average quality of the instruments of the Unground Stone Age is very low, notwithstanding that its best specimens are far above the level of the worst of the later period. These combined characters of rudeness and the absence of grinding give the remains of the Unground Stone Age an extremely important bearing on the history of Civilization, from the way in which they bring together evidence of great rudeness and great antiquity. The antiquity of the Drift implements is, as has been said, proved by direct geological evidence. The Cave implements, even of the reindeer period, are proved by their fauna to be earlier, as they are seen at a glance to be ruder, than those of the cromlech period, and of the earliest lake-dwellings of Switzerland, both belonging to the Ground Stone Age. To the student who views Human Civilization as in the main an upward development, a more fit starting-

point could scarcely be offered than this wide and well-marked progress from an earlier and lower, to a later and higher, stage of the history of human art.

To turn now to the productions of the higher or Ground Stone Age, grinding is found rather to supplement chipping than to supersede it. Implements are very commonly chipped into shape before they are ground, and unfinished articles of this kind are often found. Moreover, such things as flake-knives, and heads for spears and arrows, have seldom or never been ground in any period, early or late, for the obvious reason that the labor of grinding them would have been wasted, or worse. Flake-knives of obsidian appear to have been sometimes finished by grinding in Mexico, but most stone knives of the kind seem to have been used as they were flaked off. This question of grinding or not grinding stone implements is brought out clearly by some remarks of Captain Cook's, on his first voyage to the South Seas. He noticed that the natives of Tahiti used basalt to make their adzes of, and these it was necessary to sharpen almost every minute, for which purpose a stone and a cocoa-nut shell full of water were kept always at hand. When he saw the New Zealanders using, for the finishing of their nicest work, small tools of jasper, chipped off from a block in sharp angular pieces like a gun-flint, and throwing them away as soon as they were blunted, he concluded they did not grind them afresh because they could not. This, however, was not the true reason, as their grinding jade and other hard stones clearly shows; but it was simply easier to make new ones than to grind the old. A good set of implements of the Ground Stone Age will consist partly of instruments made by mere chipping, such as varieties of spear-heads, arrow-heads, and flake-knives, and partly of ground implements, the principal classes of which are celts, axes, and hammers.

The word celt (Latin *celtis*, a chisel) is a convenient term for including the immense mass of instruments which

have the simple shape of chisels, and might have been used as such. No doubt many or most of them were really for mounting on handles, and using as adzes or axes; but in the absence of a handle, or a place for one, or a mark where one has been, it is often impossible to set down any particular specimen as certainly a chisel, an axe, or an adze. When, however, the cutting edge is hollowed as in a gouge, it is no longer possible to use it as an axe, though it retains the other two possible uses of chisel and adze. The water-worn pebble, in which a natural edge has been made straighter and sharper by grinding, may be taken as the original and typical form of the celt. Rude South American tribes select suitable water-worn stones and rub down their edges, sometimes merely grasping them in the hand to use them, and sometimes mounting them in a wooden handle; and axes made in this way, by grinding the edge of a suitable pebble, and fixing it in a withe handle, are known in Australia. Moreover, the class to which this almost natural instrument belongs, that, namely, which has a double-convex cross section, is far more numerous and universally distributed than the double-flat, concavo-convex, triangular, or other forms.

Where artificially shaped celts are found only chipped over, in high Stone Age deposits, as in Scandinavia, they are generally to be considered as unfinished; but when celts of hard stone are found only ground near the edge, and otherwise left rough from chipping, they may be taken as denoting a rude state of art. Thus flint celts ground only near the edge are found in Northern Europe, and even in Denmark; but in general celts of the hardest stone are found, during the Ground Stone Age, conscientiously ground and polished all over, and every large celt of hard stone which is finished to this degree represents weeks or months of labor, done not so much for any technical advantage, as for the sake of beauty and artistic completeness.

The primitive hammer, still used in some places, is an

oval pebble, held in the hand. Above this comes the natural pebble, or the artificially shaped stone, which is grooved or notched to have a bent withe fastened round it as a handle, as our smiths mount heavy chisels. Above this again is the highest kind, the stone hammer with a hole through it for the handle. This is not found out of the Old World, perhaps not out of Europe; and even the Mexicans, who in many things rivalled or excelled the stone-workers of ancient Europe, do not seem to have got beyond grooving their hammers. The stone axe proper, as distinguished from the mere celt by its more complex shape, and by its being bored or otherwise fitted for a handle, is best represented in the highest European Stone Age, and in the transition to the Bronze Age.

Special instruments and varieties are of great interest to the Ethnographer, as giving individuality to the productions of the Stone Age of different times and places. Thus, the rude triangular flakes of obsidian with which the Papuans head their spears are very characteristic of their race. These spears were probably what they were using in Schouten's time — "long staves with very long sharpe things at the ends thereof, which (as we thought) were finnes of black fishes." Among celts, the Polynesian adze blade, to be seen in almost any museum, is a well-marked type; as is the American double hatchet, and an elaborately formed American knife. The Pech's knives or Pict's knives, of Shetland, made from a rock with a slaty cleavage, seem peculiar. They appear to be efficient instruments, as an old woman was seen cutting cabbage with one not long since.

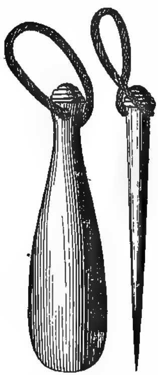
As there are a good many special instruments like these in different parts of the world, the idea naturally suggests itself of trying to use them as ethnological evidence, to prove connection or intercourse between two districts where a similar thing is found. For instance, among the most curious phenomena in the history of stone implements is the

occurrence of one of the highest types of the Stone Age, the polished celt of green jade, of all places in the world, in Australia, where the general character of the native stone implements is so extremely low. There is a quarry of this very hard and beautiful stone in Victoria, and the natives on the River Glenelg grind it into double-convex hatchet blades — a process which must require great labor; and these blades they fix with native thread into cleft sticks, and use them as battle-axes. Two of the blades in question are in the Museum of the Society of Antiquaries in Edinburgh, presented by Dr. Mackay, who got them near the place where they were made. They are only inferior to the finest celts of the same material from New Zealand, in wanting the accuracy of outline which the Maori would have given, and the conscientious labor with which he would have ground down the whole surface till every inequality or flaw had disappeared, whereas the Australian has been content with polishing into the hollow places, instead of grinding them out. Were we obliged to infer, from the presence of these high-class celts in Australia, that the natives in one part of the country had themselves developed the making of stone implements so immensely beyond the rest of their race, while they remained in other respects in the same low state of civilization, the quality of stone implements would have to be pretty much given up as a test of culture anywhere. Fortunately there is an easier way out of the difficulty. Polished instruments of this green jade have been, long ago or recently, one of the most important items of manufacture in the islands of the Indian Ocean and the Pacific, and the South Australians may have learnt from some Malay or Polynesian source the art of shaping these high-class weapons. The likelihood of this being their real history is strengthened by proofs we have of intercourse between Australia and the surrounding islands. Besides the known yearly visits of the trepang-fishers of Macassar to the Gulf of Carpentaria,

and the appearance of the outrigger-canoe in East Australia in Captain Cook's time, there is mythological evidence which seems to carry proof of connection far down the east coast.

Another coincidence of this kind may be mentioned here, though in the absence of collateral evidence it would be unwise to draw any conclusion from it. There is a well-known New Zealand weapon, the *mére*, or *pátu-pátu*. It is an edged club of bone or stone, which has been compared to a beaver's tail, or is still more like a soda-water bottle with the bulb flattened, and it is a very effective weapon in a hand-to-hand fight, being so sharp that a man's skull may be split at one blow with it. Through the neck it has a hole for a wrist-cord. The *mére* is made of the bone of a whale,

FIG. XXIV.



or of stone, and the finest, which are of green jade and worked with immense labor, were among the most precious heirlooms of the Maori chiefs. One would think that such a peculiar weapon was hardly likely to be made independently by two races; but Klemm gives a drawing of a sharp-edged Peruvian weapon, of dark brown jasper, which is so exactly like the New Zealand *mére*, even to the wrist-cord, that a single drawing of one of the latter, shown in front and profile in Fig. 24, will serve for both. There can hardly be a mistake about this weapon being really Peruvian, for another from Cuzco, of a greenish amphibolic stone, is figured by Rivero and Tschudi, curiously enough, in company with a wooden war-club, from Tunga, in Colombia, which is hardly distinguishable from a common Polynesian form. If we knew of any connection between the civilizations of Peru and the South Sea Islands, these extraordinary resemblances might be accounted for without hesitation, as caused by direct transmission.

When, however, their full value has been given to the differences in the productions of the Ground Stone Age, there remains a residue of a most remarkable kind. In the first place, a very small number of classes, flake-knives, scrapers, spear and arrow-heads, celts and hammers, take in the great mass of specimens in museums; and in the second place, the prevailing character of these implements, whether modern or thousands of years old, whether found on this side of the world or the other, is a marked uniformity. The Ethnographer who has studied the stone implements of Europe, Asia, North or South America, or Polynesia, may consider the specimens from the district he has studied, as types from which those of other districts differ, as a class, by the presence or absence of a few peculiar instruments, and individually in more or less important details of shape and finish, unless, as sometimes happens, they do not perceptibly differ at all. So great is this uniformity in the stone implements of different places and times, that it goes far to neutralize their value as distinctive of different races. It is clear that no great help in tracing the minute history of the growth and migration of tribes, is to be got from an arrow-head which might have come from Patagonia, or Siberia, or the Isle of Man, or from a celt which might be, for all its appearance shows, Mexican, Irish, or Tahitian. If an observer, tolerably acquainted with stone implements, had an unticketed collection placed before him, the largeness of the number of specimens which he would not confidently assign, by mere inspection, to their proper countries, would serve as a fair measure of their general uniformity. Even when aided by mineralogical knowledge, often a great help, he would have to leave a large fraction of the whole in an unclassed heap, confessing that he did not know, within thousands of miles or thousands of years, where and when they were made.

How, then, is this remarkable uniformity to be explained?

The principle that man does the same thing under the same circumstances will account for much, but it is very doubtful whether it can be stretched far enough to account for even the greater proportion of the facts in question. The other side of the argument is, of course, that resemblance is due to connection, and the truth is made up of the two, though in what proportions we do not know. It may be that, though the problem is too obscure to be worked out alone, the uniformity of development in different regions of the Stone Age may some day be successfully brought in with other lines of argument, based on deep-lying agreements in culture, which tend to centralize the early history of races of very unlike appearance, and living in widely distant ages and countries.

To turn to an easier branch of the subject, I have brought together here, as a contribution to the history of the Stone Age, a body of evidence which shows that it has prevailed in ancient or up to modern times, in every great district of the inhabited world. By the aid of this, it may be possible to sketch at least some rude outline of the history of its gradual decline and fall, which followed on the introduction of metal in later periods, up to our own times, when the universal use of iron has left nothing of the ancient state of things, except a few remnants, of interest to ethnologists and antiquaries, but of no practical importance to the world at large.

In the first place, there are parts of the world whose inhabitants, when they were discovered in modern times by more advanced races, were found not possessed of metals, but using stone, shell, bone, split canes, and so forth, for purposes in making tools and weapons to which we apply metals. Now, as we have no evidence that the inhabitants of Australia, the South Sea Islands, and a considerable part of North and South America, had ever been possessed of metals, it seems reasonable to consider these districts as countries where original Stone Age conditions had never

been interfered with, until they came within the range of European discovery.

But in other parts of North and South America, such interference had already taken place before the time of Columbus. The native copper of North America had been largely used by the race known to us as the "Mound Builders," who have left as memorials of their existence the enormous mounds and fortifications of the Mississippi Valley. They do not seem to have understood the art of melting copper, or even of forging it hot, but to have treated it as a kind of malleable stone, which they got in pieces out of the ground, or knocked off from the great natural blocks, and hammered into knives, chisels, axes, and ornaments. The use of native copper was by no means confined to the Mound Builders, for the European explorers found it in use for knives, ice-chisels, ornaments, etc., in the northern part of the Continent, especially among the Esquimaux and the Canadian Indians. The copper which Captain Cook found in abundance among the Indians of Prince William's Sound, was no doubt native. The iron used for arrow-heads by the Indians at the mouth of the Rio de la Plata was no doubt meteoric. This has been found in use among the Esquimaux. There is a harpoon-point of walrus tusk in the British Museum, headed with a blade of meteoric iron, and a knife, also of tusk, which is edged by fixing in a row of chips of meteoric iron along a groove. But these instruments do not appear old; they are just like those in which the Esquimaux at present mount morsels of European iron, and there is no evidence that they used their native meteoric iron, until their intercourse with Europeans in modern times had taught them the nature and use of the metal. It is indeed very strange that there should be no traces found among them of knowledge of metal-work, and of other arts, which one would expect a race so receptive of foreign knowledge to have got from contact with the Northmen, in

the tenth and following centuries; but I have not succeeded in finding any distinct evidence of the kind.

In the lower part of the Northern Continent, in Peru and some other districts of the Southern, the Stone Age was not extinct at the time of Columbus; it was indeed in a state of development hardly surpassed anywhere in the world, but at the same time several metals were in common use. Gold and silver were worked with wonderful skill, but chiefly for ornamental purposes. Though almost all the gold and silver work of Mexico has long ago gone to the melting-pot, there are still a few specimens which show that the Spanish conquerors were not romancing in the wonderful stories they told of the skill of the native goldsmiths. I have seen a pair of gold eagle ornaments in the Berlin Museum, which will compare almost with the Etruscan work for design and delicacy of finish. But what is still more important is that bronze, made of well-judged proportions of copper and tin, was in use on both continents. The Peruvians used bronze, and perhaps copper also, for tools and weapons. The Mexican bronze axe-blades are to be seen in collections, and we know by the picture-writings that both the Mexicans and the builders of the ruined cities of Central America, mounted them by simply sticking them into a wooden club, as the modern African mounts his iron axe-blade. The little bronze bells of Mexico and South America are cored castings, which are by no means novices' work, and other bronze castings from the latter country are even more remarkable.

How the arts of working gold, silver, copper, and bronze came into America, we do not know, nor can we even tell whether their appearance on the Northern and Southern Continent was independent or not. It is possible to trace Mexican connection down to Nicaragua, and perhaps even to the Isthmus of Panama, while on the other hand the northern inhabitants of South America were not unacquainted with the nations farther down the continent. But

no certain proof of connection or intercourse of any kind between Mexico and Peru seems as yet to have been made out. All that we know certainly is, that gold, silver, copper, tin, and bronze had there intruded themselves among the implements and ornaments of worked stone, though they had scarcely made an approach to driving them out of use, and that the traditions of both continents ascribe their higher culture to certain foreigners who were looked upon as supernatural beings. If we reason upon the supposition that these remarkably unanimous legends may perhaps contain historical, in combination with mythical elements, the question suggests itself, where, for a thousand or fifteen hundred years before the Spanish discovery, were men to be found who could teach the Mexicans and Peruvians to make bronze, and could not teach them to smelt and work iron? The people of Asia seem the only men on whose behalf such a claim can be sustained at all. The Massagetæ of Central Asia were in the Bronze Age in the time of Herodotus, who, describing their use of bronze for spear and arrowheads, battle-axes, and other things, and of gold rather for ornamental purposes, remarks that they make no use of iron or silver, for they have none in their country, while gold and bronze abound. Four centuries later, Strabo modifies this remark, saying that they have no silver, little iron, but abundance of gold and bronze. The Tatars were in the Iron Age when visited by mediæval travellers, and the history of the transition from bronze to iron in Central Asia, of which we seem to have here a glimpse, is for the most part obscure. The matter is, however, the more worthy of remark from its bearing on the argument for the connection of the culture of Mexico and that of Asia, grounded by Humboldt on the similarities in the mythology and the calendar of the two districts.

If we now turn to the history of the Stone Age in Asia, Africa, and Europe, we shall indeed find almost everywhere evidence of a Stone Period, which preceded a Bronze or

Iron Period; but this only to be had in small part from the direct inspection of races living without metal implements. The Kamchadals of North-eastern Asia, a race as yet ethnologically isolated, were found by the Kosak invaders using cutting-tools of stone and bone. It is recorded that with these instruments it took them three years to hollow out a canoe, and one year to scoop out one of the wooden troughs in which they cooked their food; but propably a large allowance for exaggeration must be made in this story. It is curious to notice that, thirty or forty years ago, Erman got in Kamchatka one of the Stone Age relics found in such enormous numbers in Mexico, a fluted prism of obsidian, off which a succession of stone blades had been flaked; but though one would have thought that the comparatively recent use of stone instruments in the country would have been still fresh in the memory of the people, the natives who dug it up had no idea what it was. Stone knives, moreover, have been found in the high north-east of Siberia, on the site of deserted yourts of modern date, said to have been occupied by the settled Chukchi, or Shalags.

Chinese literature has preserved various notices of the finding and use of stone implements. Such is a passage speaking of arrows with stone heads sent as tribute by the barbarians in the reign of Wu-Wang (about B. C. 1100), and two which mention the actual use of such arrows in China, whether by Chinese or Tatars, up to the thirteenth century of our era. Again, referring to Nan-hiu-fu, in the province of Kwan-tong, in Southern China, it is stated, "They find, in the mountains and among the rocks which surround it, a heavy stone, so hard that hatchets and other cutting instruments are made from it." It is to be remembered that China is inhabited not only by the race usually known to us as the Chinese, but by another, or several other far less cultured races; the mountains of Kwan-tong and the other southern provinces being especially inhabited by such rude and seemingly aboriginal tribes. There is, besides, a Chinese

tradition speaking of the use of stone for weapons among themselves in early times, which implies at least the knowledge that this is a state of things characterizing a race at a low stage of culture, and may really embody a recollection of their own early history. Fu-hi, they say, made weapons; these were of wood, those of Shin-nung were of stone, and Chi-yu made metal ones.

Among the great Tatar race to which the Turks and Mongols, and our Hungarians, Lapps, and Finns belong, accounts of a Stone Age may be found, in the most remarkable of which the widely prevailing idea that stone instruments found buried in the ground are thunderbolts, is very well brought into view. In the Chinese Encyclopædia of the Emperor Kang-hi, who began to reign in 1662, the following passage occurs: —

" '*Lightning-stones.*' — The shape and substance of lightning-stones vary according to place. The wandering Mongols, whether of the coasts of the eastern sea, or the neighborhood of the Sha-mo, use them in the manner of copper and steel. There are some of these stones which have the shape of a hatchet, others that of a knife, some are made like mallets. These lightning-stones are of different colors; there are blackish ones, others are greenish. A romance of the time of the Tang says that there was at Yu-men-si a great Miao dedicated to the Thunder, and that the people of the country used to make offerings there of different things, to get some of these stones. This fable is ridiculous. The lightning-stones are metals, stones, pebbles, which the fire of the thunder has metamorphosed by splitting them suddenly and uniting inseparably different substances. There are some of these stones in which a kind of vitrification is distinctly to be observed."

Moreover, within the last century the Tunguz of Northeastern Siberia, belonging to the same Tatar race, were using stone arrow-heads, while Tacitus long before made a similar remark as to their relatives the Finns, whose " only hope is

in their arrows, which, from want of iron, they make sharp with bones." But the Tunguz have been expert iron-workers as long as we have any distinct knowledge of them, and arrow-heads of stone and bone may survive, for an indefinite number of centuries, the main part of the Stone Age to which they properly belong. Even the Egyptians, in the height of their civilization, used stone arrow-heads in hunting, notwithstanding their vast wealth of bronze and iron. The peculiar arrows which are being shot at wild oxen in the bas-reliefs of Beni Hassan are still to be seen in collections; they are special as to their wedge-shaped flint heads, fixed with the broad edge foremost, a shape like that of the wooden-headed bird-bolts of the middle ages. The stone arrow-heads found on the battle-field of Marathon are often described, but arrow-heads and other instruments of the Stone Age are common in Greek soil, and may be præ-Aryan. It is clear, however, that metal must be very common and cheap to be used in so wasteful a way as in heading an arrow, perhaps only for a single shot.

If we go back eighteen hundred years, an account may be found of a people living under Stone Age conditions in a part of Asia much less remote than Tartary and China. Strabo gives the following description of the fish-eaters inhabiting the coast of the present Beloochistan, on the Arabian Sea, and, like the Aleutian Islanders of modern times, building their huts of the bones of whales, with their jaws for doorways: — "The country of the Ichthyophagi is a low coast, for the most part without trees, except palms, a sort of acanthus, and tamarisks; of water and cultivated food there is a dearth. Both the people and their cattle eat fish, and drink rain and well-water, and the flesh of the cattle tastes of fish. In making their dwellings, they mostly use the bones of whales, and oyster-shells, the ribs serving for beams and props, and the jaw-bones for doorways; the vertebræ they use for mortars, in which they pound their sun-dried fish, and of this, with the mixture of

a little corn, they make bread, for, though they have no iron, they have mills. And this is the less wonderful, seeing that they can get the mills from elsewhere; but how can they dress the millstones when worn down? with the stones, they say, with which they sharpen their arrows and darts [of wood, with points] hardened in the fire. Of the fish, part they cook in ovens, but most they eat raw, and they catch them in nets of palm-bark."

Though direct history gives but partial means of proving the existence of a Stone Age over Asia and Europe, the finding of ancient stone tools and weapons, in almost every district of these two continents, proves that they were in former times inhabited by Stone Age races, though whether in any particular spot the tribes we first find living there are their descendants as well as their successors, this evidence cannot tell us. How, for instance, are we to tell what race made and used the obsidian flakes which were found with polished agate and carnelian beads under the chief corner-stone of the great temple of Khorsabad? All through Western Asia, and north of the Himalaya, stone implements are scattered broadcast through the land; while China, to judge from the slender evidence forthcoming, seems to have had its Stone Age like other regions.

Japan abounds in Stone Age relics, of which Van Siebold has given drawings and descriptions in his great work; and his own collection at Leyden is very rich in specimens. The arrow-heads of obsidian, flint, chert, etc., are of types like those found elsewhere. Their presence is sometimes accounted for by stories that they were rained from the sky, or that every year an army of spirits fly through the air with rain and storm; when the sky clears, people go out and hunt in the sand for the stone arrows they have dropped. The arrow-heads are found most abundantly in the north of the great island of Nippon, in the so-called land of the Wild Men, a population who were only late and with difficulty brought under the Mikado dynasty, and who belong to

the same Aino race as the present inhabitants of the island of Jesso and the southern Kuriles. In Japan, stone celts are frequently to be found in the collections of minerals of native amateurs, and they are still sometimes dug up with other objects of stone. They seem only of average symmetry and finish. Here, again, the natives call such a stone celt a "thunderbolt," *Rai fu seki*, or *Tengu no masakari*, "battle-axe of Tengu," Tengu being the guardian of heaven. The notion is also current that they are implements of the Evil Spirit, whose symbol is the fox, whence the names of "Fox-hatchet," "Fox-plane." As a fox-plane, a double-flat celt is shown in Siebold's plates, which may have served the purpose of a plane, or, if it was fixed to a handle, that of an adze. Regularly shaped stone knives (not mere flakes) are represented; some are like the stone knives of Egypt, but rougher; the Japanese recognize them as "stone-knives." Some which have been dug up are kept in the temples as relics of the time of the Kami, the spirits or divinities from whom the Japanese hold themselves to be descended, and whose worship is the old religion of the Japanese, the way or doctrine of the Kami, more commonly known by the Chinese term Sin-tu. Some stone knives, drawn by Siebold on Japanese authority, seem to be of a slaty rock, which has admitted of their being very neatly made in curious shapes. One very highly finished specimen is called the stone knife of the "Green Dragon," a term which may be explained by the fact that the conventional dragon of Japan has a sword at the end of his tail.

Again, Java abounds in very high-class stone implements, and such things are found on the Malay Peninsula, though in both these districts the natives, unlike the Polynesians, whose language is so closely connected with theirs, do not even know what stone celts are, and hold with so many other nations that they are thunderbolts.

In India an account of the discovery by Mr. H. P. Le Me-

surier of a great number of ancient stone celts was published in 1861. He found them stored up in villages of the Jubbulpore district, near the Mahadeos, and in other sacred places; and since then many more have been met with by other observers. India has now to be reckoned among countries which afford relics not only of the Stone Age, but of its ruder period of unpolished implements, preceding the more advanced period of the ground celt.

In Europe, ancient stone implements are found from east to west, and from north to south, the relics perhaps of races now extinct, or absorbed in others, or of the Tatar population of Finland and Lapland, or of that unclassed race which survives in the Basque population about the Pyrenees, who, unlike the Finns and Lapps, cannot as yet claim relationship with a surviving parent stock.

As to our own Aryan or Indo-European race, our first knowledge of it, at the remote period of which a picture has been reconstructed by the study of the Vedas, and a comparison of the Sanskrit with other Aryan tongues, shows a Bronze Age prevailing among them when they set out on their migrations from Central Asia to found the Aryan nations, the Indians, Persians, Greeks, Germans, and the rest. A general view of the succession of metal to stone all over the world, justifies a belief that the Aryans were no exception to the general rule, and that they, too, used stone instruments before they had metal ones; but there is little known evidence bearing on the matter beyond that of a few Aryan words, which are worth mentioning, though they will not carry much weight of argument.

The nature of this evidence may be made clear, by noticing how it comes into existence in places where the introduction of metal is a matter of history. In these places it sometimes happens that old words, referring to stone and stone instruments, are transferred to metal and metal instruments, and these words take their place as relics of the Stone Age preserved in language. Thus, in North

America the Algonquin names for copper and brass are *miskwaubik* and *ozawaubik*, that is to say, "red-stone" and "yellow-stone;" while the name *e-reck*, that is, "stone," is used by some Indian tribes of California for all metals indiscriminately. In the Delaware language, *opeek* is "white," and *assuun* is "stone;" so that it is evident that the name of silver, *opussuun*, means "white-stone," while the termination "stone" is discernible in *uisauaasun*, "gold." In the Mandan language, the words *mahi*, "knife," and *mahitshuke*, "flint," are clearly connected. Having thus examples of the way in which the Stone Age has left its mark in language, in races among whom it has been superseded within our knowledge, it is natural that we should expect to find words marking the same change, in the speech of men who made the same transition in times not clearly known to history. What has been done in this way as yet comes to very little; but Jacob Grimm has set an example by citing two words, *hammer*, Old Norse *hamarr*, meaning both "hammer" and "rock," and Latin *saxum*, a name possibly belonging to a time when instruments to cut with, *secare*, were still of stone, and which still keeps close to Old German *sahs*, Anglo-Saxon *seax*, a knife. There may possibly be some connection between *sagitta*, arrow, and *saxum*, stone, and in like manner between Sanskrit *çilî*, arrow, *çilâ*, stone, while in the Semitic family of languages, Hebrew *chetz*, arrow, *châtzâtz*, gravel-stone, are both related to the verb *châtzatz*, to cut. But against the inference from these words, that their connection belongs to a time when stone was the usual material for sharp instruments, there lies this strong objection, that knife and stone might get from the same root names expressing sharpness, or any other quality they have in common, without having anything directly to do with one another, while the same word, *hamar*, may have been found an equally suitable name for "hammer"

and "rock," without the hammer being so called because all hammers were orignally stones.

Among the Semitic race, however, it seems possible to bring forward better evidence than this of an early Stone Age. If we follow one way of translating, we find in two passages of the Old Testament an account of the use of sharp stones or stone knives for circumcision; Ex. iv. 25, "And Zipporah took a stone," and Josh. v. 2, "At that time Jehovah said to Joshua, Make thee knives of stone." As they stand, however, these passages are not sufficient to prove the case, for there is much the same ambiguity as to the original meaning of *tzor*, *tzūr*, as in the etymologies of some of the words just mentioned. Gesenius refers them to *tzūr*, to cut, and the readings "an edge, a knife," and "knives of edges, *i. e.* sharp knives," have so far at least an equal claim. It remains to be seen which view is supported by further evidence.

In the first place, the Septuagint altogether favors the opinion that the knives in question were of stone, by reading in the first place a stone, or pebble, and in the second, stone knives of sharp-cut stone. These are mentioned again in the remarkable passage which follows the account of the death and burial of Joshua (Josh. xxiv. 29, 30), "And it came to pass after these things, that Joshua the son of Nun, the servant of Jehovah, died, being a hundred and ten years old, and they buried him in the border of his inheritance in Timnath Serah, which is in Mount Ephraim, on the north side of the hill of Gaash." Here follows in the LXX. a passage not in the Hebrew text which has come down to us. "And there they laid with him in the tomb wherein they buried him there, the stone knives, wherewith he circumcised the children of Israel at the Gilgals, when he led them out of Egypt, as the Lord commanded. And they are there unto this day." Any one who is disposed to see in this statement a late interpolation, may imagine an origin for it. The opening of a tumulus containing, as

they so commonly do, a quantity of sharp instruments of stone, might suggest to a Jew who only knew such things as circumcising knives, the idea that he saw before him the tomb of Joshua, and, buried with his body, the stone knives wherewith he circumcised the children of Israel.

How far the modern Jews follow the translation "stone," "knives of stone," I cannot entirely say; but two modern Jewish translations of the Pentateuch which I have consulted read "stone" in Ex. iv. 25. It is to be remarked that the Rabbinical law admits such a use; it stands thus: —

"We may circumcise with anything, even with a flint, with crystal (glass), or with anything that cuts, except with the sharp edge of a reed, because enchanters make use of that, or it may bring on a disease, and it is a precept of the wise men to circumcise with iron, whether in the form of a knife or of scissors, but it is customary to use a knife." Now, as Professor Lazarus, a most competent judge in such matters, remarked to me with reference to this question, the mere mention of a practice in the Rabbinical books is not good evidence that it ever really existed, seeing that their writers habitually exercise their fertile imaginations in devising cases which might possibly occur, and then argue upon them as seriously as though they were real matters of practical importance. But there are observed facts, which tend to bring these particular ordinances out of the region of fancy, and into that of fact. As to the prohibition of the use of the reed knife, it is to be noticed that this (in the form of a sharp splinter of bamboo) was the regular instrument with which circumcision was performed in the Fiji islands. And as to the use of the stone circumcising knife, it is stated by Leutholf, who is looked upon as a good authority, that it was in use in Æthiopia in his time — "The Alnajah, an Æthiopian race, perform circumcision with stone knives." This would be in the sixteenth century. And though the modern Jews generally

use a steel knife, there appears to be a remarkable exception to this custom; that when a male child dies before the eighth day, it is nevertheless circumcised before burial, but this is done, not with the ordinary instrument, but with a fragment of flint or glass.

Under the reservation just stated, a recognition among the Jewish ordinances of the practice of slaughtering a beast with a [sharp] stone, may here be cited from the Mishna: —

"If a person has slaughtered [a beast] with a hand-sickle, a [sharp] stone, or a reed, it is *casher*," *i. e.* clean, or fit to be eaten. Here not only the context, but the necessity of shedding the animal's blood, proves that a proper cutting instrument of stone, or at least a sharp-edged piece, is meant.

Before drawing any inference from these pieces of evidence, it will be well to bring together other accounts of the use of cutting instruments of stone, glass, etc., by people who, though in possession of iron knives, for some reason or other did not choose to apply them to certain purposes. Thus the practice of sacrificing a beast, not with a knife or an axe, but with a sharp stone, has been observed on the West Coast of Africa during the last century, as will be more fully detailed in page 357.

An often quoted instance of the use of a stone knife for a ceremonial purpose, where iron would have been much more convenient, is the passage in Herodotus which relates that, in Egypt, the mummy-embalmers made the incision in the side of the corpse with a sharp Æthiopic stone. The account given by Diodorus Siculus is fuller: "And first, the body being laid on the ground, he who is called the scribe marks on its left side how far the incision is to be made. Then the so-called slitter (parachistes), having an Æthiopic stone, and cutting the flesh as far as the law allows, instantly runs off, the bystanders pursuing him and pelting him with stones, cursing him, and, as it were, turn-

ing the horror of the deed upon him," for he who hurts a citizen is held worthy of abhorrence. There are two kinds of stone knives found in excavations and tombs in Egypt, both of chipped flint, and very neatly made; one kind is like a very small cleaver, the other has more of the character of a lancet, and would seem the more suitable of the two for the embalmer's purpose.

Noteworthy from this point of view is another description by Herodotus, that of the covenant of blood among the Arabians, where a man standing between the parties with a sharp stone made cuts in the inside of their hands, and with the blood smeared seven stones lying in the midst, calling on their deities Orotal and Alilat. A story related by Pliny, of the way in which the balsam of Judea, or "balm of Gilead," was extracted, comes under the same category. The incisions, he says, had to be made in the tree with knives of glass, stone, or bone, for it hurts it to wound its vital parts with iron, and it dies forthwith.

With regard to the reason of such practices as these, it has been suggested that there was a practical advantage in the use of the stone knife for circumcision, as less liable to cause inflammation than a knife of bronze or iron. From this point of view Pliny's statement has been quoted, that the mutilation of the priests of Cybele was done with a sherd of Samian ware, as thus avoiding danger. But the idea of a stone instrument having any practical advantage over an iron one in cutting a living subject, and even a dead body or a tree, will not meet with much acceptance. I cannot but think that most, if not all, of the series are to be explained as being, to use the word in no harsh sense, but according to what seems its proper etymology, cases of *superstition*, of the "standing over" of old habits into the midst of a new and changed state of things, of the retention of ancient practices for ceremonial purposes, long after they had been superseded for the commonplace uses of ordinary life. Such a view takes in every instance which has been

mentioned, though the reason of iron not being adopted by the modern Jews in one case as well as in another is not clear. As to Pliny's story of the balm of Gilead, I am told, on competent authority, that the use of stone and such things instead of iron for making incisions in the tree, if ever it really existed, could be nothing but a superstition without any foundation in reason. It may perhaps tell in favor of the story being true, that it is only one of a number of cases mentioned by Pliny, of plants as to which the similar notion prevailed, that they would be spoiled by being touched with an iron instrument. There seems, on the whole, to be a fair case for believing that among the Israelites, as in Arabia, Ethiopia, and Eygpt, a ceremonial use of stone implements long survived the general adoption of metal, and that such observances are to be interpreted as relics of an earlier Stone Age; while incidentally the same argument makes it probable that the rite of circumcision belonged to the Stone Age among the ancient Israelites, as we know it does among the modern Australians.

To complete the survey of the Stone Age and its traces in the world, Africa has now to be more fully examined. This great continent is now entirely in the Iron Age. The tribes who do not smelt their own iron, as the Bushmen, get their supplies from others; and in the immense central and western tracts above the Equator, there appears to be no record of tribes living without it. In South Africa, however, the case is different; and the accounts of the English voyages round the Cape of Good Hope about the beginning of the seventeenth century, collected in Purchas's "Pilgrimes," give quite a clear history of the transition from the Stone to the Iron Age, which was then taking place.

Then, as now, the inhabitants of Madagascar had their iron knives and spear-heads; and they would have silver in payment for their cattle, 1*s.* for a sheep, and 3*s.* 6*d.* for a cow. But on the West African coast, north of the Cape, there were pastoral tribes, probably Hottentots, who evi-

dently did not know then, as they do now, how to work the abundant iron ore of their country. At Saldanha Bay, in 1598, John Davis could get fat-tailed sheep and bullocks for bits of old iron and nails, and in 1604 a great bullock was still to be bought for a piece of an old iron hoop.

Stone implements from South Africa, till lately very scarce in ethnological collections, are now sent over in plenty. The Christy Museum contains arrow-heads, spear-heads, scrapers, &c.; and an adze mounted in its withe handle, which has been figured, seems to indicate modern use.

Traces of a Stone Age in Egypt, in the use of the stone arrow-head, and of the stone knife for ceremonial purposes, have been already spoken of. No account of the finding of stone implements in North Africa seems to have been published till Mr. Christy, in a journey made in Algeria in 1863, found them there. He met with flint flake-knives, arrow-heads, and polished celts, at Constantine; flakes, arrow-heads, and a beautifully chipped lance-head of quartzite at Dellys on the coast; and flakes and a large picked-shaped instrument, from the desert south-east of Oran, on the confines of Morocco. At Bou-Merzoug, on the plateau of the Atlas, south of Constantine, he found, in a bare, deserted, stony place among the mountains, a collection of tombs, one thousand or fifteen hundred in number, made of the rude limestone slabs, set up with one slab to form a roof, so as to make perfect dolmens, closed chambers where the bodies were packed in. Tradition says that a wicked people lived there, and for their sins stones were rained upon them from heaven; so they built these chambers to creep into. Near this remarkable necropolis Mr. Christy found flint-flakes and arrow-heads.

If we go westward as far as the Canary Islands, we find a race, considered to be of African origin, living in the fourteenth century under purely Stone Age conditions, making hatchets, knives, lancets, and spear-heads of obsidian, and

axes of green jasper, and pointing their spears and digging-sticks with horns. It is possible that they might have once had the use of iron, and have lost it on removing to the islands, where there is no ore; but no evidence of this having been the case seems to have been found.

In Western Africa, when the god Gimawong came down to his temple at Labode on the Gold Coast once a year, with a sound like a flight of wild geese in spring, his worshippers sacrificed an ox to him, killing it not with a knife, but with a sharp stone. Klemm looks upon this as a sign of the high antiquity of the ceremony, and, taking into consideration the evidence as to the keeping up of the use of stone for ceremonial purposes into the Iron Age, the inference seems a highly probable one, although there is another side to this argument. In order to bring this into view, and to adduce some other facts bearing on evidence of the Stone Age, it will be necessary to say here something more of the Myth of the Thunderbolt.

For ages it has been commonly thought that, with the flash of lightning, there falls, sometimes at least, a solid body which is known as the thunder-bolt, thunder-stone, etc., as in the dirge in "Cymbeline,"—

> "Fear no more the lightning-flash,
> Nor the all-dreaded thunder-stone."

The actual falling of meteoric stones may have had to do with the growth of this theory; but whatever its origin, it is one of the most widely spread beliefs in the world. The thing considered to be the thunderbolt is not always defined in accounts given. It is described as a stone, or it may be a bit of iron-ore, or perhaps iron, or a belemnite. Dr. Falconer mentions the name of "lightning-bones" or "thunder-bones," given to fossil bones brought down as charms from the plateau of Chanthan in the Himalayas, where, of course, frequen thunder-storms are seen to account for their presence. But it is also believed that the

stone celts and hammers found buried in the ground are thunderbolts. The country folks of the West of England still hold that the "thunder-axes" they find, fell from the sky, and the Shetlanders agree in the opinion. In Brittany, the itinerant umbrella-mender of Carnac inquires on his rounds for *pierres de tonnerre*, and takes them in payment for repairs; and these are fair examples of what may be found in other countries in Europe, and not in those inhabited by our Aryan race alone, for the Finns have the same belief. The remarkable Chinese account of the thunder-stones has been already quoted, and it has been noticed that stone celts are held to be thunderbolts in Japan and the Eastern Archipelago. Even in a country where the use of stone axes by the Indians is matter of modern history, and in some places actually survives to this day, the Brazilians use, for such a stone axe-blade, their Portuguese word *corisco*, that is, "lightning," "thunderbolt."

As the stone axes and hammers are but one of several classes of objects thought to be thunderbolts, it is probable that the myth took them to itself at a time when their real use and nature had been forgotten, and the reason of their being found buried underground was of course unknown. This view is supported by the fact of the existence of such instruments being also accounted for by taking them up into mythology in other ways. Thus in Japan the stone arrow-heads are rained from heaven, or dropped by the flying spirits who shoot them, while in Europe they are fairy weapons, *albschosse*, *elf-bolts*, shot by fairies or magicians, and in the North of Ireland the wizards still draw them out from the bodies of "overlooked" cattle. Dr. Daniel Wilson mentions an interesting post-Christian myth, which prevailed in Scotland till the close of the last century, that the stone hammers found buried in the ground were Purgatory Hammers for the dead to knock with at the gates.

The inability of the world to understand the nature of the

stone implements found buried in the ground is not more conspicuously shown in the myths of thunderbolts, elfin arrows, and purgatory hammers, than in the sham science that has been brought to bear upon them in Europe, as well as in China. It is instructive to see Adrianus Tollius, in his 1649 edition of "Boethius on Gems," struggling against the philosophers. He gives drawings of some ordinary stone axes and hammers, and tells how the naturalists say that they are generated in the sky by a fulgureous exhalation conglobed in a cloud by the circumfixed humor, and are as it were baked hard by intense heat, and the weapon becomes pointed by the damp mixed with it flying from the dry part, and leaving the other end denser, but the exhalations press it so hard that it breaks out through the cloud, and makes thunder and lightning. But, he says, if this be really the way in which they are generated, it is odd that they are not round, and that they have holes through them, and those holes not equal through, but widest at the ends. It is hardly to be believed, he thinks. Speculation on the natural origin of high-class stone weapons and tools has now long since died out in Europe, but some faint echoes of the Chinese emperor's philosophy were heard among us but lately, in the arguments on the natural formation of the flint implements in the Drift.

With regard, then, to the use of thunderbolts as furnishing evidence of an early Stone Age, it may be laid down that such a myth, when we can be sure that it refers to artificial stone implements, proves that such things were found by a people who, being possessed of metal, had forgotten the nature and use of these rude instruments of earlier times. Kang-hi's remarks that some of the so-called "lightning-stones" were like hatchets, knives, and mallets, and Pliny's mention of some of the thunder-stones being like axes, are cases in point. But the mere mention of the belief in thunderbolts falling, as for example in Madagascar and Arracan, only gives a case for further inquiry on the

suspicion that the thunderbolts in these regions may turn out to be stone implements, as they have so often done elsewhere.

The thunderbolt is thought to have a magical power, and there is especially one notion, in connection with which it comes into use. This is, that it preserves the place where it is kept from lightning, the idea being apparently here, as in the belief about the "wildfire" which will be presently mentioned, that where the lightning has struck, it will not strike again, so that the place where a thunderbolt is put is made safe by having been already struck once, though harmlessly. In Shetland the thunderbolts (which are stone axes) protect from thunder, while in Cornwall the stone hatchets and arrow-heads, which fall from the clouds where the thunder produced them, announce by change of color a change of weather. In Germany, the house in which a thunderbolt is kept is safe from the storm; when a tempest is approaching, it begins to sweat, and again it is said of it, that "he who chastely beareth this, shall not be struck by lightning, nor the house or town where that stone is," while nearly the same idea comes out in Pliny's account of the *brontia*, which is "like the heads of tortoises, and falling, as they think, with thunder, puts out, if you will believe it, what has been struck by lightning."

In the mythology of our race, the bolt of the Thunder-god holds a prominent place. To him, be he Indra or Zeus the Heaven-god, or the very thunder itself in person, Thunor or Thor, the Aryans give as an attribute the bolt which he hurls with lightning from the clouds. Now, it is possible that this was the meaning of the Roman Jupiter Lapis. The sacred flint was kept in the temple of Jupiter Feretrius, and brought out to be sworn by, and with it the pater patratus smote the victim slain to consecrate the solemn treaties of the Roman people. "'If by public counsel,' he said, 'or by wicked fraud, they swerve first, in that day, O Jove, smite thou the Roman people, as I

here to-day shall smite this hog; and smite them so much more, as thou art abler and stronger.' And having said this, he struck the hog with a flint stone."

To those who read this, it will seem probable that the flint of Jupiter was held either to be a thunderbolt or to represent one, and the practice cannot be taken as having of necessity come down from an early Stone Age, seeing that it might quite as well have sprung up among a race possessed of metals. The sacred instrument is commonly spoken of indefinitely, as *lapis silex*, *saxum silex*, but it may have been a flint implement found buried in the ground, for already in the ancient song of the "Arval Brethren," the thunderbolt is spoken of as a celt, and, as has been shown, at least this development of the myth of the thunderbolt belongs to an age when the nature of the buried stone implement has been forgotten. Yet if all we knew about the matter was, that victims were sacrificed with a flint on certain occasions, and that the Fetiales carried these flints with them into foreign countries where a treaty was to be solemnized, it might be quite plausibly argued that we had here before us a practice which had come down, unchanged, from the time when the fathers of the Roman race used stone implements for the ordinary purposes of life. This is the other side of the argument, which must not be kept out of sight in interpreting, as a relic of the Stone Age, the West African ceremony of slaughtering the beast on the yearly sacrifice to Gimawong, not with a knife, but with a sharp stone.

The examination of the evidence bearing on the Stone Age thus brings into view two leading facts. In the first place, within the limits of the Stone Age itself, an unmistakable upward development in the course of ages is to be discerned, in the traces of an early period when stone implements were only used in their rude chipped state, and were never ground or polished, followed by a later period when grinding came to be applied to improve

such stone instruments as required it. And in the second place, a body of evidence from every great district of the habitable globe uniformly tends to prove, that where man is found using metal for his tools and weapons, either his ancestors or the former occupants of the soil, if there were any, once made shift with stone. It would be well to have the evidence fuller from some parts of the world, as from Southern Asia and Central Africa, but we need not expect from thence anything but confirmation of what is already known.

13. Theory of a Nervous Ether.

BY DR. RICHARDSON, F. R. S.

IN a recent course of experimental lectures on medical science, I broached a modification of the old and well-nigh obsolete theory of the existence of a nervous fluid; and I have since reduced to some form, in a published lecture, the ideas I wished to set forth. It has been curious to me to observe the different lights in which this effort has been viewed by men of different phases of thought and knowledge. Some physicists have accepted that the theory suggests the existence of an intermediate agency between the matter of living bodies and the forces by which the matter is moved — an agency essential to the correct understanding of the relations coexisting between the living matter and force. Others have thought the theory obscure and retrogressive, a kind of retreat into 'the bosom of Van Helmont, and of those fanciful heroes of Lord Lytton, who, still professing Helmontism as an article of scientific, and I had almost said moral faith, proclaim life to be " a gas." Lastly,

certain enthusiastic writers, and, as they call themselves, experimenters, have actually laid hold of the theory to support modern spiritualism, and its idola of the theatre.

To commence with the last of these critics, I need scarcely say, in relation to them, that there is nothing in my mind bearing in the remotest degree on their arguments. I speak only of a veritable material agent, refined, it may be, to the world at large, but actual and substantial: an agent having quality of weight and of volume; an agent susceptible of chemical combination, and thereby of change of physical state and condition; an agent passive in its action, moved always, that is to say, by influences apart from itself, obeying other influences; an agent possessing no initiative power, no *vis*, or *energia naturæ*, but still playing a most important, if not a primary part in the production of the phenomena resulting from the action of the *energia* upon visible matter.

In respect to those who imagine that the theory of the existence of a nervous ether tends to materialize the phenomena of life and of living action, the answer is simple. The theory treats of an assumed material part of the living organism, and has no reference whatever to that more distant or spiritual essence of our nature of which, as yet, no more is known, physically, than of the *energia naturæ* itself. We must all accept that the impulses of men and animals, the volitions, the sympathies, the passions, are manifested by and through the material organism, the matter as a mechanism obeying the force that moves it. The tongue of man that speaks, the hand that gives, takes, strikes, aids, begs; the feet that make progression, and all parts that act, act positively as mechanisms of material character. How they act, in obedience to the impulses that move them, becomes, consequently, a distinct question that may be studied apart from the impulses themselves, and in the theory this is implied. The impulses, I mean, are considered as initial and independent motions, the

origin of which forms no part whatever of the theory of a nervous ether.

Of the first order of critics, they alone appreciate the meaning I would attach to the theory of a nervous or animal ether. The idea attempted to be conveyed by the theory is, that between the molecules of the matter, solid or fluid, of which the nervous organism, and indeed of which all the organic parts of the body are composed, there exists a refined, subtile medium, vaporous or gaseous, which holds the molecules in a condition for motion upon each other, and for arrangement and rearrangement of form; a medium by and through which all motion is conveyed; by and through which the one organ or part of the body is held in communion with the other parts, and by and through which the outer living world communicates with the living man: a medium which, being present, enables the phenomena of life to be demonstrated, and which, being universally absent, leaves the body actually dead — in such condition, i. e. that it cannot, by any phenomenon of motion, prove itself to be alive.

I hope I have now made clear what is generally meant by the theory of a nervous ether. But there are yet two other points on which it is essential, for a moment, to dwell. In using the word *ether*, I do not necessarily convey the common idea of a body belonging to the chemical family or group called the ethers, or the ethyl series. I use the word ether in its general sense, as meaning a very light vaporous or gaseous matter: I use it, in short, as the astronomer uses it when he speaks of the ether of space, by which he means a subtle but material medium, the chemical composition of which he has not yet discovered. Again, when I speak of a *nervous* ether, I do not convey that the ether is existent in nervous structure only: I believe, truly, that it is a special part of the nervous organization; but as nerves pass into all structures that have capacities for movement and sensibilities, so the nervous ether passes into all such

parts; and as the nervous ether is, according to my view, a direct product from blood, so we may look upon it as a part of the atmosphere of the blood.

The theory of the existence and influence of a nervous *fluid* is old. The earliest practical neuro-physiologists seized upon it at once as affording the only explanation of many vital phenomena. Willis, who was the leader of modern neuro-physiology, gave the cue, and after him, up to the time of Galvani, every school taught the theory. "There exists," said the masters, "there exists in the nervous system a distinct fluid, a liquid which proceeds from the centres towards and to the extremities of the nervous system. The nervous centres (the brain included) are thus positively glands; they secrete the nervous fluid, and pour it out by the nerves. As bile is secreted by the liver and poured forth, so is the nervous fluid secreted by its centres and poured forth by the nerve ducts." Alexander Munro, in 1783, sums up the argument clearly and tersely, to the effect that the nerves are tubes or ducts conveying a fluid secreted in the brain, the cerebellum, and spinal marrow.

To the physiologists from the time of Willis (who lived, by the way, in the reign of Charles II.), and to those who followed him up to the time when Galvani made his first observations on so-called animal electricity (1790), this hypothesis of a nervous fluid sufficed to explain the varied phenomena of nervous function; the fluid was supposed to convey the vibrations of the outer world to the inner centres of the animal body; the fluid governed secretion; the fluid was the channel by which, or rather through which, the volitional powers of the animal were brought to bear on the muscular mechanism.

Nor must it be ignored that the arguments employed in support of the theory were sensible, and were supported by experimental facts. "When," argued the maintainers of the theory, "when we cut a nerve across and bring its parts,

again into contiguity, we do not restore the office of the nerve immediately, nay, the influence of the nerve beyond the incision is generally not restored; when we compress a nerve, we produce numbness by the compression; and when, by repeated slight compressions of a nerve, we cause repeated contractions of the muscles fed by the nerves, we prove that the impulse is exerted on matter which admits of being affected *by simple pressure*."

Still further, the argument of the velocity with which impressions are conveyed from the centres of the nervous system to the muscles, or from the external surfaces back to the centres, — an argument which in our times has been advanced as if it were new in science, — was studied by these earlier physiologists, who urged that if the nerves are constantly filled or charged with fluid, an impulse given to that fluid at the brain may be suddenly communicated to the most distant organ, or the reverse, although the velocity of the fluid be itself very small.

The modern reader will gather from the above that there was great simplicity, great beauty, great force, in the olden theory of a nervous fluid; and if I could invite him to follow me into the subject of structure of nervous matter, he might perchance be more convinced that the theory was in a sense true and unassailable. He would certainly wonder why so little is known, at this day, about so important a speculation.

His wonder would, moreover, be most reasonable, for the theory, while it has never been successfully assailed, never been injured a jot by anything that has been said about it, has merely been let drop and forgotten, hidden for a time by the brilliancy of another theory, now well nigh blazed out — I mean the electrical theory promulgated by Galvani.

The evidence in favor of the existence of an elastic medium pervading the nervous matter, and capable of being influenced by simple pressure, is all-convincing. When we press a nerve firmly, we act on something that is as dis-

tinctly under the influence of the pressure, as when we press upon a vein and by that means influence the current of blood within the vein. When we freeze a nerve we stop its function altogether, we make it almost like metal in its appearance and physical character, and we can then divide it without communicating the faintest scintillation of sensation to the brain.* In this case the cold has acted like pressure; it has either condensed the nervous matter, and has, by the contraction induced, driven out some agent the presence of which was necessary for the performance of function, or it has condensed the agent itself together with the nerve, so that the condition for sensation is suspended. When we divide a nerve we break a connection, we divide a structure which must be absolutely perfect for conveyance of motion, and with our best skill we cannot secure that the connection shall be ever again rendered perfect.

Each one of these experimental facts suggests that there exists in the nerve an actual material mobile agent, a something more than the solid matter which the eye can see and the finger touch. The question to be considered is, the *nature* of this agent.

In nervous structure there is, unquestionably, a true nervous fluid, as our predecessors taught. The precise chemical composition of this fluid is not yet well known; the physical characters of it have been little studied. Whether it moves in current we do not know; whether it circulates we do not know; whether it is formed in the centres and passes from them through the nerves, or whether it is formed everywhere where blood enters nerve we do not know. The exact uses of the fluid we do not, consequently, know.

It occurs to my mind, however, that the veritable fluid of

* This fact is well illustrated in the operation of nerving the horse, under ether spray. The nerve, when exposed, is found superficially frozen, and when frozen more deeply may be cut as if it were a soft metallic wire, dead to the knife as in the nerveless horny hoof below.

nervous matter is not of itself sufficient to act as the subtle medium that connects the outer with the inner universe of man and animal. I think — and this is the modification I suggest of the older theory — there must be another form of matter present during life; a matter which exists in the condition of vapor or gas, which pervades the whole nervous organism, surrounds, as an enveloping atmosphere, each molecule of nervous structure, and is the medium of all motion communicated to or from the nervous centres.

The source of this refined matter, within the body, is, I think, the blood. I look upon it as a vapor distilled from blood, as being persistently formed so long as the blood circulates at the natural temperature, and is being diffused into the nervous matter, to which it gives quality for every function performed by the nervous organization. In the closed cavities containing nervous structures, the cavities of the skull and spinal column, this gaseous matter, or ether as I have called it, sustains a given requisite tension; in all parts of the nervous structure it surrounds the molecules of nervous matter, separates them from each other, and is yet, between them, a bond and medium of communication.

When it is once fairly presented to the mind that during life there is in the animal body a finely diffused form of matter, a vapor filling every part, and even stored in some parts; a matter constantly renewed by the vital chemistry; a matter as easily disposed of as the breath, after it has served its purpose, — a new flood of light breaks on the intelligence. Our own consciousness re-echoes to us the fact. Our experience assures us that between ourselves and the outer world there is, while we live, an intercommunicating bond which connects us with the outer world; which is apart from the gross visible substances we call flesh, bone, brain, blood; which, in some way, nevertheless, is connected with both heart and brain and organs of sense; which is made in

and within our own organism; which, produced in over quantity, oppresses us; which, produced in too small quantity, is insufficient for our wants; which is renewed by food and by sleep, exhausted by wakefulness and labor; which receives every vibration or motion from without, and lets the same vibrate into us, to be fixed or reflected back; and which conveys the impulse when we will an act and perform it.

It may be urged that in this line of thought is included no more than the theory of the existence of the ether that is supposed to pervade space, the undulating ether of light. It may be said that this universal ether pervades all the organism of the animal body as from without, and as part of every organization. This view would be Pantheism physically discovered, if it were true. It fails to be true because it would destroy the individuality of every individual being; it fails to be true because it would destroy the individuality of every individual sense. If we did not individually produce, by our own chemistry, the refined essence pervading us; if the essence were diffused through us independently of our eating, drinking, breathing, we should be independent of the earth altogether, endowed with an indestructible physical existence not belonging to us at all, specially, but to the universe at large, and distinct from us; we should, in fact, be as atoms of matter aggregated by attraction into a certain form or mould, and held to the earth by the attraction of the earth, but actually permeated with the ether, as though we floated in an etheral sea. If we did not individually produce the medium of communication between ourselves and the outer world, if it were produced from without and adapted to one kind of vibration alone, then were fewer senses required than we possess; for, taking two illustrations only — ether of light is not adapted for sound, and yet we hear as well as see; while air, the medium of motion of sound, is not the medium of light, and yet we see and hear.

In the theory, therefore, I offer, the nervous ether is an animal product. In different classes of animals it may differ in physical quality so as to be adapted to the special wants of the animal, but essentially it plays one part in all animals, and is produced in all, in the same way.

I think I may venture, to some extent, to define the required physical properties of a nervous ether. We may consider it as a gas or vapor, and as having in its elementary construction carbon, hydrogen, and possibly nitrogen: I suspect it is condensable under cold, movable under pressure, diffusible by heat, insoluble in the blood, and holding at the natural temperature of the body a tension requisite for natural function. It is retained, I imagine, for a longer time in cold-blooded animals, after death, than in warm-blooded animals, and longer in warm-blooded animals that have died in cold than those that have died in heat. Upon its presence for a considerable time after death in some animals, and for a short time in all animals under favoring conditions, I believe to depend those post-mortem movements of muscles which Haller attributed to the *vis insita* of muscular fibre.

The nervous ether is not, according to my ideal of it, in itself active or an excitant of animal motion in the sense of a force; but it is essential as supplying the conditions by which the motion is rendered possible. It is the conductor, I presume, of all vibrations of heat, of light, of sound, of electrical action, of mechanical friction. It holds the nervous system throughout in perfect tension during perfect states of life. By exercise it is disposed of, and when the demand for it is greater than the supply, its deficiency is indicated by nervous collapse or exhaustion. It accumulates in the nervous centres during sleep, bringing them, if I may so speak, to their due tone, and therewith rousing the muscles to awakening or renewed life. The body, fully renewed by it, presents capacity for motion, fulness of form, life. The body, bereft of it, presents inertia, the configuration of

"shrunk death" the evidence of having lost something physical that was in it when it lived.

The theory of a nervous ether comports itself well in respect to the refined mechanism of the senses. When the wave of atmosphere strikes the tympanum or drum of the ear it communicates the vibration to the nervous ether within, and so, by the auditory tract, to the central organ, the brain. When the wave of luminous ether impinges on the condensing retina it communicates the vibration, through the nervous ether, along the optic tract, to the brain. When the picture of an object is put upon the retina, it is looked at where it is put, on the veritable spot where it is focussed, until it evanishes by being withdrawn or shut off from the sense. When an impression is made on the surface of the body, be it made by heat, electricity, or mechanical excitation, it is vibrated through the ether to the centres of the nervous system; and when an impulse from the centres is conveyed to the muscles, it, too, is vibrated through the same medium.

The ether, as I opine, holds the molecules and cells of nervous matter, the ultimate particles of muscles, the corpuscles of blood, and probably the ultimate particles of the fibrine of the blood, in a state of mobility; it thus passively counteracts the attraction of cohesion between particles, and prevents rigidity of the flexible or fluid structures of the body so long as they live. Being itself a simple physical agent, the nervous ether is, I apprehend, influenced in the most signal manner by simple external conditions. It is influenced by variations of heat and cold, is increased in volume by heat, is contracted or condensed by cold; it is influenced by atmospheric pressure; it is influenced by electrical conditions of the air; the inductive effects of electricity on the muscles of living animals are due, as it seems to me, to the disturbance excited by the electrical action upon the animal atmosphere; nay, I conceive, we ourselves are rendered conscious of the changes

of external conditions — of heat, of cold, of variations of the barometrical pressure, of electrical storms — by the sensible fluctuations of the atmosphere within us.

Through the nervous ether, itself a gas or vapor, other gases or vapors may readily and quickly diffuse, and by such diffusion may so modify the physical characters of the natural ether as to lead to modifications of nervous function. Thus those vapors which, being diffused into the body, produce benumbing influence — as the vapors of alcohol, chloroform, bichloride of methylene, ethylic ether, and the like — produce their benumbing effects because they are not capable of taking the place of the natural ether into which they diffuse; they interfere, that is to say, with the physical conduction of impressions through what should be the pure atmosphere between the outer and the inner world. A dense cloud in the outer atmosphere shall shut out my view of the sun; a cloud in the inner atmosphere of my optic tract shall produce precisely the same obscurity.

Pain is the result of rapid vibration of the nervous ether; and pain, whether it be called physical or mental, is the same event. The so-called physical pain, that which comes from a blow or a cut, is excessive vibration, more than the brain can receive. The so-called mental pain is excessive vibration carried through the senses to the centres, or excited in the centres and carried to the outlets of the body for relief.

It is, I think, no figure of speech to say that nerves bleed — no figure of speech to affirm the phenomena of nervous exhaustion, of nervous collapse, of nervous strain, and of nervous overstrain. Under mental labor or emotion nerves bleed as vessels do — bleed not blood in mass, but the richest product of blood. Under violent shock the whole nervous atmosphere is thrown into vehement vibration, the heart is held fixed by the commotion, and the failure of animal force is followed by sudden and overwhelming prostration. These

are all clear physical phnomena. A feeble animal chemistry yields a feeble nervous tension, a powerful chemistry or action produces over-tension.

The infliction of physical pain is followed by the shriek, the sob, the moan, or the hard setting of muscles; the shriek, the sob, the moan, or the muscular rigor is the echo of the pain; it is more, it is the outlet of the evil, the excess of vibration reflected, diverted, given forth. The infliction of mental pain is followed by tears, sighs, and other varied forms of grief; these are, again, the echoes and the outlets of the evil.

The tension of the nervous ether *generally* may be too high or too low; it may be so *locally*, owing to local changes in the nervous matter it invests and charges. Under undue tension of the brain or cord, both closed firmly in by bony walls, the ether, under sharp excitation, may vibrate as if in a storm, and plunge every muscle under cerebral or spinal crontrol into uncontrolled motion — unconscions convulsion.

Lastly, the nervous ether may be poisoned; it may, I mean, have diffused through it, by simple gaseous diffusion, other gases or vapors derived from without; it may derive from within products of substances swallowed and ingested, or gases of decomposition produced, during disease, in the body itself. But here a field of observation opens relative to the production of some forms of acute and chronic diseases on which I must not enter, were even space at command.

I have tried, and I hope with success, to offer a simple and practical view of a very difficult subject. The philosopher may think the subject void, the public may think it obscure. There are many, I am aware, who will say that although the theory is reasonable it is comparatively worthless until more is known — until, in short, the physical character of the assumed nervous ether is demonstrated and certain definite phenomena are made manifest by its mediation. This criticism, which I should

be the first to suggest, I am the last to ignore. I profess only at the present moment to submit a theory; I look to experiment for the trial of the theory, its truth, its falsity; and as it is a theory which experiment can slowly, but in the most striking and solemn manner, truly and faithfully try, I abide the result with leisure and contentment.

14. Toads in the Hole.

"IN cutting the Inverness and Perth Railway through the Lochnavandah Park on Altyre," says Sir A. R. Gordon Cumming, "we have unceremoniously trespassed on the privacy and retirement of a numerous colony of ancient toads. The cutting is here from twenty to twenty-five feet deep, the lower part being through from ten to sixteen feet of freestone and red conglomerate. The interesting old residenters are found in the red freestone about fifteen to twenty feet below the surface, where they certainly must have seen several nineteen years' leases out on the land above them. They are sometimes turned out by the heavy handpick or the great iron crowbar; but a blast of powder, of which a vast amount is here expended, seems to cause the greatest upset in the establishment, as a shot is sometimes the means of exposing as many as a dozen of the sleepy old fellows. They seem none the worse for their long repose; but after giving a few winks at the 'new light' thus suddenly let in upon them, and taking several gasps of the unwonted air, they leisurely and deliberately proceed to hop and crawl down the line, along the small water-course, towards the lower fields. I have seen them in numbers, and some of the men have counted above forty at once." — *Elgin Courier.*

15. The Origin of Metalliferous Deposits.

An Address by T. STERRY HUNT, F. R. S., *before the Polytechnic Association of the American Institute of New York.*

THERE are about sixty bodies which chemists call elements; the simplest forms of matter which they have been able to extract from the rocky crust of our earth, its waters, and its atmosphere. These substances are distributed in very unequal quantities, and in very different manners. As regards the frequency of these elements in nature, neglecting for the present those which constitute air and water, and confining ourselves to the solid matters of the earth's crust, there are a few which are exceedingly abundant, making up nine tenths, if not ninety-five hundredths, of the rock so far as known to us. The bases, of which silica, alumina, lime, magnesia, potash, and soda are oxides, are very common, and occur almost everywhere. There are, however, other elements which are much rarer, being found in comparatively small quantities. Many of these rarer elements are, however, of great importance in the economy of nature. Such are the common metals and other substances used in the arts, which occur in nature in quantities relatively very minute, but which have been collected by various agencies, and thus made available for the wants of man. It is chiefly of the well-known metals, iron, copper, silver, and gold, that I propose to speak to-night; but there are two other elements, not classed among the metals, which I shall notice, for the reason that their history is extremely important, and will, moreover, enable us to comprehend more clearly some points in that of the metals themselves. I speak of phosphorus and iodine.

You all know the essential part which the former of these, combined as phosphate of lime, plays in the animal economy, in the formation of bones; and how plants require for their proper growth and development a certain amount of phosphorus. Ordinary soils contain only a few thousandths of this element, yet there are agencies at work in nature which gather this diffused phosphorus together in beds of mineral phosphates, and in veins of crystallized apatite, which are now sought to enrich impoverished soils. Iodine, an element of great value in medicine, and in the art of photography, is widely distributed, but still rarer than phosphorus, yet it abounds in certain mineral waters, and is, moreover, accumulated in marine plants. These extract it from the waters of the sea, where iodine exists in such minute quantities as almost to elude our chemical tests.

There are probably no perfect separations in nature. We cannot, without great precautions, get any chemical element in a state of absolute purity, and we have reason to believe that even the rarest elements are everywhere diffused in infinitesimal quantities. The spectroscope, which we have lately learned to apply to the investigation alike of the chemistry of our own earth and that of other worlds, once supposed to be beyond the chemist's ken, not only demonstrates the very wide diffusion of various chemical elements here on earth, but shows us that very many of them exist in the sun. If we accept, as most of us are now inclined to do, the nebular hypothesis, and admit that our earth was once, like the sun of to-day, an intensely heated vaporous mass; that it is, in fact, a cooled and condensed portion of that once great nebula of which the sun is also a part, we might expect to find all the elements now discovered in the sun distributed throughout this consolidated globe. We may speculate about the condensation of some of these before others, and their consequent accumulation in the inner parts of the earth, but the fact that we have all the elements of the solar envelope, together with many more, in the exterior portions of our

planet, shows that there was, at least, but a very partial concentration and separation of these elements during the period of cooling and condensation. The superficial crust of the earth, from which all the rocks and minerals which we know have been generated, must have contained, diffused through it, from the earliest time, all the elements which we now meet with in our study of the earth, whether still diffused or accumulated, as we often find the rarer elements, in particular veins or beds.

The question now before us is, how have these elements thus been brought together, and why is it that they are not all still widely and universally diffused? Why are the compounds of iron in beds by themselves, copper, silver, and gold gathered together in veins, and iodine concentrated in a few ores and certain mineral waters? That we may the better discern the direction in which we are to look for the solution of this problem, let us premise that all of these elements, in some of their combinations, are more or less soluble in water. There are, in fact, no such things in nature as absolutely insoluble bodies, but all, under certain conditions, are capable of being taken up by water, and again deposited from it. The alchemists sought in vain for a universal solvent; but we now know that water, aided in some cases by heat, pressure, and the presence of certain widely-distributed substances, such as carbonic acid and alkaline carbonates and sulphides, will dissolve the most insoluble bodies; so that it may, after all, be looked upon as the long-sought-for alkahest or universal menstruum.

Let us now compare the waters of rivers, seas, and subterranean springs, thus impregnated with various chemical elements, with the blood which circulates through our own bodies. The analysis of the blood shows it to contain albuminoids which go to form muscle, fat for the adipose tissues, phosphate of lime for the bones, fluorides for the enamel of the teeth, sulphur which enters largely into the composition of the hair and nails, soda which accumulates in the bile,

and potash, which abounds in the flesh-fluid. All of these are dissolved in the blood, and the great problem for the chemical physiologist is to determine how the living organism gathers them from the complex fluid, depositing them here and there, and giving to each part its proper material. This selection is generally ascribed to a certain vital force, peculiar to the living body. I shall not here discuss the vexed question of the nature of the force which determines the assimilation from the blood of these various matters for the needs of the animal organism further than to say that modern investigations tend to show that it is only a subtler kind of chemistry, and that the study of the nature and relation of colloids and crystalloids, and of the phenomena of chemical diffusion, promises to subordinate all these obscure physiological processes to chemical and physical laws.

Let us now see how far the comparison which we have made between the earth and an animal organism will help us to understand the problem of the distribution of minerals in nature; how far water, the universal solvent, acting in accordance with known chemical and physical laws, will cause the separation of the mixed elements of the earth's crust, and their accumulation in veins and beds in the rocks. The subject is one of great importance to the geologist, who has to consider the genesis of the various rocks and ore deposits, and the relations, which we are only beginning to understand, between certain metals and particular rocks, and between certain classes of ores and peculiar mineralogical and geological conditions. It is at the same time a vast one, and I can to-night only give you a few illustrations of the chemistry of the earth's crust, and of the laws of the terrestrial circulation, which I have compared to that of the blood distributing throughout the animal frame the elements necessary for its growth. The analogy is not altogether new, since a great French geologist, Elie de Beaumont, has already spoken of a terrestrial circulation in regard to certain elements in the earth's crust; though he has not, so far as I am aware, car-

ried out to the extent which I propose to-night in my attempt to explain some of the laws which have presided over the distribution of metals in the earth.

The chemist in his laboratory takes advantage of changes of temperature, and of the action of various solvents and precipitants, to separate, in the humid way, one element from another; but to these agencies, in the economy of nature, are added others, which we have not yet succeeded in imitating, and which are effected only in growing animals and plants. I repeat it, I do not wish to say that these latter processes are different in kind from those which we command in our laboratories, but rather that these organisms control a far finer and more delicate chemical and physical apparatus than we have yet invented. Plants have the power of selecting from the media in which they live the elements necessary for their support. The growing oak and the grass alike assimilate from the air and waters the carbon, hydrogen, nitrogen, and oxygen which build up their tissues, and at the same time take from the soil a portion of phosphorus, which, though minute, is in both cases essential to the vegetable growth. The acorn of the oak and the grass alike become the food of animals, and the gathered phosphates pass into their bones, which are nearly pure phosphate of lime. In like manner the phosphates from organic waste and decay find their way to the sea, and through the agency of marine vegetation become at last the bony skeletons of fishes. These are, in turn, the prey of carnivorous birds, whose exuviæ form on tropical islands beds of phosphatic guano. A history not dissimilar will explain the origin of beds of coprolites, and other deposits of mineral phosphates.

But again, these plants or these animals may perish in the sea, and be buried in its ooze. The phosphates which they have gathered are not lost, but become fixed in an insoluble form in the clayey matter; and when, in the revolutions of ages, these sea-muds, hardened to rock, become dry land,

and crumble again to soil, the phosphates are there found ready for the wants of vegetation.

Most of what I have said of phosphates applies equally to the salts of potash, which are not less necessary to the growing plant. From the operation of these laws, it results that neither of these elements is found in large quantities in the ocean. This great receptacle of the drainage from the land contains still smaller quantities of iodine; in fact, the traces of this element present in sea water can scarcely be detected by our most delicate tests. Yet marine plants have the power of separating this iodine, and accumulating it in their tissues, so that the ashes of these plants are not only rich in phosphates and in potash-salts, but contain so much iodine that our supplies of this precious element are almost wholly derived from this source, and that the gathering and burning of sea-weed for the extraction of iodine is in some regions an important industry. When this marine vegetation decays, the iodine which it contains appears, like the potash and phosphates, to pass into combinations with metals, earths, or earthy phosphates, which retain it in an insoluble state, and in certain cases yield it to percolating saline solutions, which thus give rise to springs rich in iodine.

In all of these processes the action of organic life is direct and assimilative, but there are others in which its agency, although indirect, is not less important. I can hardly conceive of an accumulation of iron, copper, lead, silver, or gold, in the production of which animal or vegetable life has not either directly or indirectly been necessary, and I shall begin to explain my meaning by the case of iron. This, you are aware, is one of the most widely-diffused elements in nature; all soils, all growing plants contain it; and it is a necessary element in our blood. Clays and loams contain, however, at best two or three hundredths of the metal, but so mixed with other matters that we could never make it available for the wants of this iron age of ours. How does

it happen that we also find it gathered together in great beds of ore, which furnish an abundant supply of the metal? The chemist finds that the iron, as diffused in the rocks, exists chiefly in combination with oxygen, with which it forms two principal compounds: the first, or protoxide, which is readily soluble in water impregnated with carbonic acid or other feeble acids, and the second, or peroxide, which is insoluble in the same liquids. I do not here speak of the magnetic oxide, which may be looked upon as a compound of the other two, neutral and indifferent to most natural chemical agencies. The combinations of the first oxide are either colorless, or bluish, or greenish in tint, while the peroxide is reddish-brown, and is the substance known as iron-rust. Ordinarily brick clays are bluish in color, and contain combined iron in the state of protoxide, but when burned in a kiln they become reddish, because this oxide absorbs from the air a further proportion of oxygen, and is converted into peroxide. But there are clays which are white when burned, and are much prized for this reason. Many of these were once ferruginous clays, which have lost their iron by a process everywhere going on around us. If we dig a ditch in a moist soil which is covered with turf or with decaying vegetation, we may observe that the stagnant water which collects at the bottom soon becomes coated with a shining, iridescent scum, which looks somewhat like oil, but is really a compound of peroxide of iron. The water as it oozes from the soil is colorless, but has an inky taste from dissolved protoxide of iron. When exposed to the air, however, this absorbs oxygen, and peroxide is formed, which is no longer soluble, but separates as a film on the surface of the water, and finally sinks to the bottom as a reddish ochre, which is chiefly peroxide of iron; or, under somewhat different conditions, becomes aggregated as a massive iron ore. A process identical in kind with this has been at work at the earth's surface ever since there were decaying organic matters, dissolving the iron from the porous rocks, clays, and sands, and

gathering it together in beds of iron ore or iron ochre. It is not necessary that these rocks and soils should contain the iron in the state of protoxide, since these organic products (which are themselves dissolved in the water) are able to remove a portion of the oxygen from the insoluble peroxide, and convert it into the soluble protoxide of iron, being themselves, in part, oxidized and converted into carbonic acid in the process.

We find in rock formations of very different ages beds of sediment which have been deprived of iron by organic agencies, and near them will generally be found the accumulated iron. Go into any coal region, and you will see evidences that this process was at work when the coal beds were forming. The soil in which the coal plants grew has been deprived of its iron, and when burned turns white, as do most of the slaty beds from the coal rocks. It is this ancient soil which constitutes the so-called fire clays, prized for making fire bricks, which, from the absence of both iron and alkalies, are very infusible. Interstratified with these we often find, in the form of iron-stone, the separated metal; and thus from the same series of rocks may be obtained the fuel, the ore, and the fire clay.

From what I have said, it will be understood that great deposits of iron ore generally occur in the shape of beds; although waters holding the compounds of iron in solution have, in some cases, deposited them in fissures or openings in the rocks, thus forming true veins of ore, of which we shall speak farther on. I wish now to insist upon the property which dead and decaying organic matters possess of reducing protoxide, and rendering soluble the insoluble peroxide of iron diffused through the rocks, and reciprocally the power which this peroxide has of oxidizing and consuming these same organic matters, which are thereby finally converted into carbonic acid and water. This last action, let me say in passing, is illustrated by the destructive action of

rusting iron fastenings on moist wood, and the effect of iron stains in impairing the strength of linen fibre.

We see in the coal formation that the vegetable matter necessary for the production of the iron-ore beds was not wanting; but the question has been asked me, Where are the evidences of the organic material which was required to produce the great beds of iron ore found in the ancient crystalline rocks? I answer that the organic matter was, in most cases, entirely consumed in producing these great results; and that it was the large proportion of iron diffused in the soils and waters of these early times which not only rendered possible the accumulation of such great beds of ore, but oxidized and destroyed the organic matters, which, in later ages, appear in coals, lignites, pyroschists, and bitumens. Some of the carbon of these early times is, however, still preserved in the form of graphite, and it would be possible to calculate how much carbonaceous material was consumed in the formation of the great iron-ore beds of the older rocks, and to determine of how much coal or lignite they are the equivalents.

In the course of ages, however, as a large proportion of the once diffused iron oxide has become segregated in the form of beds of ore, and thus removed from the terrestrial circulation, the conditions have grown more favorable for the preservation of the carbonaceous products of vegetable life. The crystalline, magnetic, and specular oxides, which constitute a large proportion of the ores of this metal, are almost or altogether indifferent to the action of organic matter. When, however, these ores are reduced in our furnaces, and the resulting metal is exposed to the oxidizing action of a moist atmosphere, it is again converted into iron rust, which is soluble in water holding organic matters, and may thus be made to enter once more into the terrestrial circulation.

There is another form in which iron is frequently concentrated in nature, that of sulphide, and most frequently as the bisulphide, known as iron pyrites. This substance is found

both in the oldest and the newest rocks, and, like the oxide of iron, is even to-day forming in certain waters and in beds of mud and silt, where it sometimes takes a beautifully crystalline shape. What are the conditions in which the sulphide of iron is formed and deposited, instead of the oxide or carbonate of iron? Its production depends, like these, on decaying organic matters. The sulphates of lime and magnesia, which abound in sea-water, and in many other natural waters, when exposed to the action of decaying plants or animals, out of contact of air, are, like peroxide of iron, deoxidized, and are thereby converted into soluble sulphides; from which, if carbonic acid be present, sulphuretted hydrogen gas is set free. Such soluble sulphides, or sulphuretted hydrogen, are the reagents constantly employed in our laboratories to convert the soluble compounds of many of the common metals, such as iron, zinc, lead, copper, and silver into sulphides, which are insoluble in water and in many acids, and are thus conveniently separated from a great many other bodies. Now, when in a water holding iron oxides, sulphates are also present, the action of organic matter, deoxidizing the latter, furnishes the reagent necessary to convert the iron into a sulphide; which in some conditions, not well understood, contains two equivalents of sulphur for one of iron, and constitutes iron pyrites. I may here say, that I have found that the unstable protosulphide, which would naturally be first formed, may, under the influence of a persalt of iron, lose one half of its combined iron; and that from this reaction a stable bisulphide results. This subject of the origin of iron pyrites is still under investigation.

The reducing action of organic matters upon soluble sulphates is well seen in the sulphuretted hydrogen which is evolved from the stagnant sea-water in the hold of a ship, and which coats silver exposed to it with a black film of sulphide of silver, and for the same reason discolors white-lead paint. The presence of sulphur in the exhalations from some other decaying matters is well known, and in all these

cases a soluble compound of iron will act as a disinfectant, partly by fixing the sulphur as an insoluble sulphide. Silver coins brought from the ancient wreck of a treasure ship in the Spanish Main were found to be deeply incrusted with sulphide of silver, formed in the ocean's depths by the process just explained, which is one that must go on wherever organic matters and sea-water are present, and atmospheric oxygen excluded.

The chemical history of iron is peculiar; since it requires reducing matters to bring it into solution, and since it may be precipitated alike by oxidation, and by further reduction, provided sulphates are present. The metals, copper, lead, and silver, on the contrary, form compounds more or less soluble in water, from which they are not precipitated by oxygen, but only by reducing agents, which may separate them in some cases in a metallic state, but more frequently as sulphides. The solubility of the salts and oxides of these metals in water is such that they are found in many mineral springs, in the waters that flow from certain mines, and in the ocean itself, the waters of which have been found to contain copper, silver, and lead. Why, then, do not these metals accumulate in the sea, as the salts of soda have done during long ages? The direct agency of organic life comes again into play, precisely as in the case of phosphorus, iodine, and potash. Marine plants, which absorb these from the sea-water, take up at the same time the metals just named, traces of all of which are found in the ashes of sea-weeds. Copper, moreover, is met with in notable quantities in the blood of many marine molluscous animals, to which it may be as necessary as iron is to our own bodies. Indeed, the blood of man, and of the higher animals, appears never to be without traces of copper as well as iron.

In the open ocean the waters are constantly aerated, so that soluble sulphides are never formed, and the only way in which these dissolved metals can be removed and converted into sulphides is by fixing them in organisms, either vegetable

or animal. These, by their decay in the mud of the bottom, or the lagoons of the shore, generate the sulphides which fix their contained metals in an insoluble form, and thus remove them from the terrestrial circulation.

It is not, however, in all cases necessary to invoke the direct action of organisms to separate from water the dissolved metals. It often happens that the waters containing these, instead of finding their way to the ocean, flow into lakes or enclosed basins, as in the case of the drainage waters of an English copper mine, which have impregnated the turf of a neighboring bog to such an extent that its ashes have been found a profitable source of copper. Under certain conditions, not yet well understood, this metal is precipitated by organic matters in the metallic state, but if sulphates are present, a sulphide is formed. Thus, in the slates of Mansfeld, in Germany, sulphide of copper is found incrusting the remains of fishes, and in the sandstones of New Jersey we find it penetrating the stems of ancient trees. I have in my possession a portion of a small trunk taken from the mud of a spring in Ontario, in which the yet undecayed wood of the centre is seen to be incrusted by hard metallic iron pyrites. In like manner the old trees of the New Jersey sandstone became incrusted with copper sulphide, which, as decay went on, in great part replaced the woody tissue. Similar deposits of sulphides of copper and of iron often took place in basins where the organic matter was present in such a condition or in such quantity as to be entirely decomposed, and to leave no trace of its form, unlike the examples just mentioned. In this way have been formed fahl-bands, and beds of pyrites and other ores.

The fact that such deposits are associated with silver and with gold leads to the conclusion that these metals have obeyed the same laws as iron and copper. It is known that both persalts of iron and soluble sulphides have the power of rendering gold soluble, and its subsequent deposition in the metallic state is then easily understood.

I have endeavored by a few illustrations to show you by what processes some of the more common metals are dissolved and again separated from their solution in insoluble forms. It now remains to say somewhat of the geological relations of ore deposits, which are naturally divided into two classes, the first including those which occur in beds, and have been formed contemporaneously with the enclosing earthy sediments. Such are the beds of iron ores, which often hold embedded shells and other organic remains, and the copper-bearing strata already mentioned, in which the metal must have been deposited during the decay of the animal or plant which it incrusts or replaces. But there are other ore deposits evidently of more recent formation than the rocky strata which enclose them, which have resulted from a process of infiltration, filling up fissures with the ore, or diffusing it irregularly through the rock. It is not always easy to distinguish between the two classes of deposits. Thus a fissure may, in some cases, be formed and filled between two sundered beds, from which may result a vein that may be mistaken for an interposed stratum. Again, a bed may be so porous that infiltrating waters may diffuse through it a metallic ore, or a metal, in such a manner as to leave it doubtful whether the process was contemporaneous with the disposition of the bed, or posterior to it. But I wish to speak of deposits which are evidently posterior, and occupy fissures in previously formed strata, constituting true veins. Whether produced by the great movements of the earth's crust, or by the local contraction of the rocks (and both of these causes have, in different cases, been in operation), such fissures sometimes extend to great lengths and depths, their arrangement and dimensions depending very much on the texture of the rocks which have been subjected to fracture. When a bone in our bodies is broken, nature goes to work to repair the fractured part, and gradually brings to it bony matter, which fills up the little interval, and at length makes the severed parts one again. So when there

are fractures in the earth's crust, the circulating waters deposit in the openings mineral matters, which unite the broken portions, and thus make whole again the shattered rocks. Vein-stones are thus formed, and are the work of nature's conservative surgery.

Water, as we have seen, is a universal solvent, and the matters which it may bring and deposit in the fissures of the earth are very various. There is scarcely a spar or an ore to be met in the stratified rocks that is not also found in some of these vein-stones, which are often very heterogeneous in composition. In certain veins we find the elements of limestone or of granite, and these often include the gems, such as amethyst, topaz, garnet, hyacinth, emerald, and sapphire, while others abound in native metals or in metallic oxides or sulphides. The nature of the materials thus deposited depends very much on conditions of temperature and of pressure, which affect the solvent power of the liquid, and still more upon the nature of the adjacent rocks and of the waters permeating them. The chemistry of mineral veins is very complicated. Many of these fissures penetrate to a depth of thousands of feet of the earth's crust, and along the channels thus opened the ascending, heated subterranean waters may receive in their course various contributions from the overlying strata. From these additions, and from the diminished solubility resulting from a decrease of pressure, deposits of different minerals are formed upon the walls, and the slow changes in composition are often represented by successive layers of unlike substances. The power of these waters to dissolve and bring from the lower strata their contained metals and spars is probably due, in great part, to the alkaline carbonates and sulphides which these waters often hold in solution; but the chemical history of the deposition of the ores of iron, lead, copper, silver, tin, and gold, which are found in these veins, demands a lengthened study, and would furnish not less beautiful examples of nature's chemistry than those I have already laid before you.

The process of filling veins has been going on from the earliest ages; we know of some which were formed before the Cambrian rocks were deposited, while others are still forming, as the observations of Phillips have shown us in Nevada, where hot springs rise to the surface and deposit silica, with metallic ores, which incrusts the walls of the fissure. These thermal waters show that the agencies which, in past times, gave rise to the rich mineral deposits of our western regions are still at work there.

Let us now consider the beneficent results of the process of vein-making. The precious metals, such as silver, are so sparsely distributed that even the beds, rich in the products of decaying sea-weed, which we have supposed to be deposited from the ocean, would contain too little silver to be profitably extracted. But in the course of ages these sediments, deeply buried, are lixiviated by permeating solutions, which dissolve the silver diffused through a vast mass of rock, and subsequently deposit it in some fissure — it may be in strata far above — as a rich silver ore. This is nature's process of concentration.

We learn from the history which we have just sketched the important conclusion that, amid all the changes of the face of the globe, the economy of nature has remained the same. We are apt, in explaining the appearances of the earth's crust, to refer the formation of ore beds and veins to some distant and remote period, when conditions very unlike the present prevailed, when great convulsions took place, and mysterious forces were at work. Yet the same chemical and physical laws are now, as then, at work, in one part dissolving the iron from the sediments, and forming ore beds, in another separating the rarer metals from the ocean's waters; while in still other regions the consolidated and buried sediments are permeated by heated waters, to which they give up their metallic matters, to be subsequently deposited in veins. These forces are always in operation, rearranging the chaotic admixture of elements, which results from the

constant change and decay around us. The laws which the First Great Cause imposed upon this material universe on the first day are still irresistibly at work fashioning its present order. One great design and purpose is seen to bind in necessary harmony the operations of the mineral with those of the vegetable and animal worlds, and to make all of these contribute to that terrestrial circulation which maintains the life of our mother earth.

While the phenomena of the material world have been looked upon as chemical and physical, it has been customary to speak of those of the organic world as vital. The tendency of modern investigation is, however, to regard the processes of animal and vegetable growth as themselves purely chemical and physical. That this is to a great extent true must be admitted, though I am not prepared to concede that we have in chemical and physical processes the whole secret of organic life. Still we are, in many respects, approximating the phenomena of the organic world to those of the mineral kingdom; and we, at the same time, learn that these so far interact and depend upon each other that we begin to see a certain truth underlying the notion of those old philosophers, who extended to the mineral world the notion of a vital force, which led them to speak of the earth as a great living organism, and to look upon the various changes in its air, its waters, and its rocky depths as processes belonging to the life of our planet.

[Since this lecture was delivered, I have seen the results of the researches of Sonstadt on the iodine in sea-water, which appear in the Chemical News for April 26, May 17, and May 24. According to him this element exists in sea-water, under ordinary conditions, as iodate of calcium, to the amount of about one part of the iodate in two hundred and fifty thousand parts of the water. This compound, by decaying organic matter, and by most other reducing agents, is changed to iodide, from which, apparently by the action of carbonic acid, iodine is set free, and may be separated by

agitating the water with bisulphide of carbon. The iodine thus liberated from sea-water by the action of dead organic matters, however, slowly decomposes water in presence of carbonate of calcium, and is reconverted into iodate, the oxygen of the air probably intervening to complete the oxidation, since, according to Sonstadt, iodides are readily converted into iodates under these conditions. He finds that the insolubility of the iodides of silver and of copper is so great that, by the use of salts of these metals, iodine may be separated from sea-water, without concentration, provided the iodate of calcium has first been reduced to iodide. By this property of iodine and its compounds to oxidize and be oxidized in turn, Sonstadt supposes them to perform the important function of consuming the products of organic decay, and so maintaining the salubrity of the ocean's waters. Their action would thus be very similar to that of the oxides of iron, as explained in the present lecture.]

16. Rotundity of the Earth.

A FRUITLESS attempt has been made for some years past to induce the belief that the earth is a flat surface; and a Mr. Hampden, who seems to have been persuaded that it is so, rashly risked five hundred pounds on the issue of an experiment on the Bedford Level, in order to test the truth of the assertion. His offer was taken up by Mr. A. R. Wallace, and arrangements satisfactory to Mr. Hampden having been made, the experiment was tried by means of three disks, rising forty-two feet above the level of the surface of a piece of water large enough to show the curvature, if there were any. The referee decided against Mr. Hampden, the central disk rising considerably above the line formed by the two outer disks, as seen from one end through a selected and approved telescope. The curvature to and fro in six miles to the extent of about five feet was proved.

17. The Phenomena of Sleep.

BY DR. RICHARDSON, F. R. S.

"THE twinkling of oblivion," as Wordsworth exquisitely defines the phenomena of sleep, has, from the time of Hippocrates to the present hour, engaged the attention of thoughtful minds. Poets have found in the phenomena subject-matter for some of the most perfect of their works. Menander exalts sleep as the remedy for every disease that admits of cure; Shakespeare defines it, "The birth of each day's life, sore labor's bath;" Sir Philip Sydney designates it, "The poor man's wealth, the prisoner's release;" and wearied Dryden sings of it, —

> "Of all the powers the best.
> O, peace of mind, repairer of decay!
> Whose balms renew the limbs to labors of the day."

As to the philosophers and the physicians who have said and written on sleep, I dare hardly think of them, lest I should commit myself to an historical volume instead of a short physiological essay; so I leave them, except such as are simply physiological, and proceed on my way.

Perfect sleep is the possession, as a rule, of childhood only. The healthy child, worn out with its day of active life, suddenly sinks to rest, sleeps its ten or twelve hours, and wakes, believing, feeling that it has merely closed its eyes and opened them again, so deep is its twinkle of oblivion. The sleep in this case is the nearest of approaches to actual death, and at the same time presents a natural paradox, for it is the evidence of strongest life.

During this condition of perfect sleep, what are the physiological conditions of the sleeper? Firstly, all the senses are

shut up, yet are they so lightly sealed that the communication of motion by sound, by mechanical vibration, by communication of painful impression, is sufficient to unseal the senses, to arouse the body, to renew all the proofs of existing active life. Secondly, during this period of natural sleep, the most important changes of nutrition are in progress; the body is renovating, and, if young, is actually growing; if the body be properly covered, the animal heat is being conserved, and laid up for expenditure during the waking hours that are to follow; the respiration is reduced, the inspirations being lessened in the proportion of six to seven as compared with the number made when the body is awake; the action of the heart is reduced; the voluntary muscles, relieved of all fatigue, and with the extensors more relaxed than the flexors, are undergoing repair of structure, and recruiting their excitability; and the voluntary nervous system, dead for the time to the external vibration, or, as the older men called it, "stimulus," from without, is also undergoing rest and repair, so that, when it comes again into work, it may receive better the impressions it may have to gather up, and influence more effectively the muscles it may be called upon to animate, direct, control.

Thirdly, although in the organism during sleep there is suspension of muscular and nervous power, there is not universal suspension; a narrow, but at the same time safe, line of distinction separates the sleep of life from the sleep of death. The heart is a muscle, but it does not sleep; and the lungs are worked by muscles, and these do not sleep; and the viscera, which triturate and digest food, are moved by muscles, and these do not sleep; and the glands have an arrangement for the constant separation of fluids, and the glands do not sleep: and all these parts have certain nerves which do not sleep. These all rest, but they do not cease their functions. Why is it so?

The reason is, that the body is divided into two systems as regards motion. For every act of the body we have a sys-

tem of organs under the influence of the will, the voluntary, and another system independent of the will, the involuntary. The muscles, which propel the body and are concerned in all acts we essay to perform, are voluntary; the muscles, such as the heart and the stomach, which we cannot control, are involuntary. Added to these are muscles which, though commonly acting involuntarily, are capable of being moved by the will: the muscles which move the lungs are of this order, for we can, if we wish, suspend their action for a short time, or quicken it; these muscles we call semi-voluntary. In sleep, then, the voluntary muscles sleep, and the nervous organs, which stimulate the voluntary muscles, sleep; but the involuntary and the semi-voluntary muscles and their nerves merely rest; they do not veritably sleep.

This arrangement will be seen, at once, to be a necessity, for upon the involuntary acts the body relies for the continuance of life. In disease the voluntary muscles may be paralyzed, the brain may be paralyzed; but if the involuntary organs retain their power, the animal is not dead. Sir Astley Cooper had under his care a man who had received an injury of the skull, causing compression of the brain, and the man lay for weeks in a state of persistent unconsciousness and repose; practically he slept. He did not die, because the involuntary system remained true to its duty; and when the great surgeon removed the compression from the brain of the man, the sleeper woke from his long trance, and recovered. Dr. Wilson Philip had a young dog that had no brain, and the animal lay in profound insensibility for months, practically asleep; but the involuntary parts continued uninfluenced, and the animal lived, and, under mechanical feeding, grew fat. Fluorens had a brainless fowl that lived in the same condition. It neither saw nor heard, he says, nor smelled, nor tasted, nor felt; it lost even its instincts; for, however long it was left to fast, it never voluntarily ate; it never shrunk when it was touched, and when attacked by its fellows, it made no attempt at self-defence, neither resisting

nor escaping. In fine, it lost every trace of intelligence, for it neither willed, remembered, felt, nor judged; yet it swallowed food, when the food was put into its mouth, and fattened. In these cases, as in that of the injured man, the involuntary systems sustained the animal life. It is the same in sleep.

When we look at these phenomena, as anatomists, we find a reason for them in structure and character of parts. The involuntary muscles have a special anatomical structure, and the nervous organism, that keeps the involuntary muscles in action, is a distinct organism. There are, briefly, two nervous systems, one locked up in the bony cavity of the skull, and in the bony canal of the spine, with nerves issuing therefrom to the muscles, and another lying within the cavities of the body, with nerves issuing from it to supply all the involuntary muscles. The first of these systems, consisting of the brain, the spinal cord, and the nerves of sense, sensation, and motion, is called the cerebro-spinal or voluntary system of nerves; the second, consisting of a series of nervous ganglia, with nerves which communicate with the involuntary muscles, and with nerves of the voluntary kind, is called, after Harvey, the vegetative, after Bichat, the organic system.

In sleep the cerebro-spinal system sleeps; the organic system retains its activity. Thus in sleep the voluntary muscles and parts fail to receive their nervous stimulation; but the involuntary receive theirs still, and under it move in steady motion; while the semi-voluntary organs also receive sufficient stimulation to keep them in motion.

Of all the involuntary organs, the heart, which is the citadel of motion, is most protected. To itself belongs a special nervous centre, that which feeds it steadily with stimulus for motion; from the cervical ganglia of the organic nervous system it receives a second or supplementary supply; and from the brain it receives a third supply, which, passive under ordinary circumstances, can, under extraordinary

circumstances, become active, and exert a certain controlling power. Then the arteries, which supply the heart with blood, are the first vessels given off from the great feeding arterial trunk, and the veins of the heart, winding independently round it, empty their contents direct again into it. Thus is the heart the most perfect of independencies; thus, during sleep and during wakefulness, it works its own course, and, taking first care of itself in every particular, feeds the rest of the body afterwards; thus, even when sleep passes into death, the heart, in almost every case, continues its action for some time after all the other parts of the organism are in absolute quiescence; thus, in hybernating animals, the heart continues in play during their long somnolence; and thus, under the insensibility produced by the inhalation of narcotic gases and vapors, the heart sustains its function when every other part is temporarily dead. Next the heart in independent action is the muscle called the midriff or diaphragm, and, as the diaphragm is a muscle of inspiration, the respiratory function plays second to the circulatory, and the two great functions of life are, in sleep, faithfully performed. In sleep of illness, bordering on sleep of death, how intently we watch for the merest trace of breath, and augur that if but a feather be moved by it, or a mirror dimmed by it, there is yet life.

In natural sleep, then, sleep perfect and deep, that half of our nature which is volitional is in the condition of inertia. To say, as Blumenbach has said, that in this state all intercourse between mind and body is suspended, is more, perhaps, than should be said, the precise limits and connections of mind and body being unknown. But certainly the brain and spinal cord, ceasing themselves to receive impressions, cease to communicate to the muscles they supply stimulus for motion, and the muscles under their control, with their nerves, therefore sleep. And so, to the extent that the acts of the brain, and cord, and their nerves are mental, and the acts or motions of the voluntary muscles are bodily acts, to

that extent, in sleep, the intercourse between the mind and the body is suspended.

THE PHYSICAL CAUSE OF SLEEP.

In sleep, the condition of the voluntary muscles and of the voluntary nervous system is, we must assume, in some manner modified, since these organs are transformed from the active into the passive state. Respecting the condition of the muscles in sleep, no study of a systematic sort has been carried out; but in relation to the brain there has been much thoughtful study, upon which many theories have been founded.

The older physiologists regarded sleep as due to the exhaustion of the nervous fluid; during sleep, they held, this fluid accumulates in the brain; and, when the brain and the other centres and nerves of the cerebro-spinal system are, to employ a common expression, recharged, the muscles are stimulated, and the body awakes, the brain prepared to receive external impressions and to animate the muscles, and the muscles renovated and ready to be recalled into activity. This theory held its ground for many years, and, perhaps, still there are more believers in it than in any other. It fails to convince the sceptical because of its incompleteness, for it tells nothing about the nature of the presumed nervous fluid, and we know nothing as yet about this fluid. The primary step of the speculation is consequently itself purely hypothetical.

Another theory that has been promulgated is, that sleep depends on the sinking or collapse of the laminæ of the cerebellum or little brain. This theory is based on the experiment that compression of the cerebellum induces sleep; but the argument is fallacious, because pressure on the larger brain, or cerebrum, is followed by the same result. The theory of pressure has been proposed again in a different way; it has been affirmed that the phenomena of sleep are caused by the accumulation of fluids in the cavity of the

cranium, and by pressure, resulting from this accumulation, on the brain as a whole. We know well that pressure upon the brain does lead to an insensible condition resembling sleep, and in some instances, in which the skull has been injured, and an artificial opening through it to the brain has been formed, pressure upon the exposed surface has led to a comatose condition. I once myself saw a case of this nature. But the evidence against this explanation is strong, because the sleeping brain has been observed to be pale, and too free of blood to convey any idea of pressure.

In opposition to the pressure theory, Blumenbach contended that sleep is due to a diminished flow and impulse of blood upon the brain, for he argued the phenomena of sleep are induced by exhaustion, and particularly by exhaustion following upon direct loss of blood. Recently Mr. Arthur Durham, in a very able communication, has adduced a similar view, and the general conclusion now is, that during sleep the brain is really supplied with less blood than in waking hours.

To account for the reason why the brain is less freely fed with blood in sleep, it has been surmised that the vessels, the arteries, which feed the brain, and which for contractile purposes are supplied with nerves from the organic nervous system, are, under their nervous influence, made to close so that a portion at least of the blood which enters through them is cut off on going to sleep. This view, however, presupposes that the organic nervous centres, instead of sharing in the exhaustion incident to labor, put forth increased power after fatigue; an idea incompatible with all we know of the natural functions.

Carmichael, an excellent physiologist, thought that sleep was brought on by a change in the assimilation of the brain, and by what he called the deposition of new matter in the organ, but he offered no evidence in proof: while Metcalfe, one of the most learned physicists and physicians of our time, maintained that the proximate cause of sleep is an ex-

penditure of the substance and vital energy of the brain, nerves, and voluntary muscles, beyond what they receive when awake, and that the specific office of sleep is the restoration of what has been wasted by exercise; the most remarkable difference between exercise and sleep being, that during exercise the expenditure exceeds the income; whereas during sleep the income exceeds the expenditure. The idea of Metcalfe expresses, probably, a broad truth, but it is too general to indicate the proximate cause of sleep, to explain which is the object of his proposition.

My own researches on the proximate cause of sleep — researches which of late years have been steadily pursued — lead me to the conclusion that none of the theories as yet offered account correctly for the natural phenomena of sleep, although, I must express, that some of them are based on well-defined facts. It is perfectly true that exhaustion of the brain will induce phenomena so closely allied to the phenomena of natural sleep that no one could tell the artificially induced from the natural sleep; and it is equally true that pressure upon the brain will also lead to a state of sleep simulating the natural. For example, in a young animal, a pigeon, I can induce the deepest sleep by exposing the brain to the influence of extreme cold. I have had a bird sleeping calmly for ten hours under the local influence of cold. During this time the state of the brain is one of extreme bloodlessness, and when the cold is cautiously withdrawn, and the brain is allowed to refill gently with blood, the sleep passes away. This is clear enough, and the cold, it may be urged, produces contraction of the brain substance and of the vessels, with diminution of blood, and with sleep as the result. But if, when the animal is awaking from this sleep induced by cold, I apply warmth for the unsealing of the parts a little too freely, if, that is to say, I restore the natural warmth too quickly, then the animal falls to sleep again under an opposite condition; for now, into the relaxed vessels of the brain, the heart injects blood so freely that the

vessels, in like manner as when the frozen hand is held near the fire, become engorged with blood, there is congestion, there is pressure, and there is sleep.

The same series of phenomena, from opposite conditions, can be induced by narcotic vapors. There is a fluid called chloride of aonyl, which, by inhalation, causes the deepest sleep; during the sleep so induced, the brain is as bloodless as if it were frozen. There is an ether called methylic, which, by inhalation, can be made to produce the deepest sleep; during this sleep the vessels of the brain are engorged with blood.

We are, therefore, correct in supposing that artificial sleep may be induced both by removal of blood from the brain and by pressure of blood upon the brain, and in the facts there is, when we consider them, nothing extraordinary. In both conditions, the natural state of the brain is altered; it cannot, under either state, properly receive or transmit motion; so it is quiescent; it sleeps. The experimental proof of this can be performed on any part of the body where there is nerve-fibre and blood-vessel; if I freeze a portion of my skin, by ether spray, I make it insensible to all impression — I make it sleep; if I place over a portion of skin a cupping-tube, and forcibly induce intense congestion of vessels, by exhausting the air of the tube, I make the part also insensible — I make it sleep.

The two most plausible theories of sleep — the plenum and the vacuum theories I had nearly called them — are then based on facts; but still I think them fallacious. The theory that natural sleep depends on pressure of the brain from blood is disproved by the observations that have been made of the brain during sleep, while the mechanism of the circulation through the brain furnishes no thought of this theory as being possibly correct. The theory that sleep is caused by withdrawal of blood from the brain by contraction of its arterial vessels, is disproved by many considerations. It presupposes that, at the time when the cerebro-spinal ner-

vous system is most wearied, the organic system is most active; and it assumes that the great volume of blood which circulates through the brain can be cut off without evidence of increased volume of blood and tension of vessel in other parts of the body; a supposition directly negatived by the actual experiment of cutting off the blood from the brain.

There is another potent objection, applicable to both theories. When sleep is artificially induced, either by subjecting the brain to pressure of blood or to exhaustion of blood, the sleep is of such a kind that the sleeper cannot be roused until the influence at work to produce the sleep is removed. But in natural sleep the sleeper can always be roused by motion or vibration. We call to a person supposed to be sleeping naturally, or we shake him, and if we cannot rouse him, we know there is danger; but how could these simple acts remove pressure from the brain, or relax the contracted vessels feeding the brain?

These two theories set aside, the others I have named need not trouble us; they are mere generalizations, interesting to read, worthless to pursue. Know we, then, nothing leading towards a solution of the question of the proximate cause of sleep? I cannot say that, for I think we see our way to something which will unravel the phenomena; but we must work slowly and patiently, and as men assured that in the problem we are endeavoring to solve we are dealing with a subject of more than ordinary importance. I will try to point out the direction of research.

I find that to induce sleep it is not necessary to produce extreme changes of brain matter. In applying cold, for example, it is not necessary to make the brain substance solid in order to induce stupor, but simply to bring down its temperature ten or twelve degrees. I find also that very slight direct vibrations, concussions, will induce stupor; and I find that in animals of different kinds the profoundness of sleep is greater in proportion as the size of the brain is larger. From these and other facts I infer that the phenomena of

natural sleep is due to a molecular change in the nervous structure itself of the cerebro-spinal system, and that in *perfect* sleep the *whole* of the nervous structure is involved in the change — the brain, the cord, the nerves; while in imperfect sleep only *parts* of this nervous matter are influenced. This is in accord with facts, for I can by cold put to sleep special parts of the nervous mass without putting other parts to sleep. In bad sleep we have the representation of the same thing in the restlessness of the muscles, the half conscious wakings, the dreams.

Suppose this idea of the change of nervous matter to be true, is there any clew to the nature of the change itself? I think there is. The change is one very closely resembling that which occurs in the solidification of water surcharged with a saline substance, or in water holding a hydrated colloid, like dialyzed silica, in trembling suspension. What is, indeed, the brain and nervous matter? It is a mass of water made sufficiently solid to be reduced into shape and form, by rather less than twenty per cent. of solid matter, consisting of albuminous substance, saline substance, fatty substance. The mechanism for the supply of blood is most delicate, membranous; the mechanism for dialysis, or separation of crystalloidal from colloidal substance, is perfect, and the conversion of the compound substance of brain from one condition of matter to another is, if we may judge from some changes of water charged with colloidal or fatty substances, extremely simple. I do not now venture on details respecting this peculiarly interesting question, but I venture so far as to express what I feel will one day be the accepted fact, that the matter of the wakeful brain is, on going to sleep, changed, temporarily, into a state of greater solidity; that its molecular parts cease to be moved by external ordinary influences, by chemical influences; that they, in turn, cease to communicate impressions, or, in other words, to stimulate the voluntary muscles; and that then there is sleep which lasts until there is re-solution of structure, whereupon

there is wakefulness from renewed motion in brain matter, and renewed stimulation of voluntary muscle through nerve.

The change of structure of the brain, which I assume to be the proximate cause of sleep, is possibly the same change as occurs in a more extreme degree when the brain and its subordinate parts actually die. The effects of a concussion of the brain from a blow, the effects of a simple puncture of nervous matter in centres essential to life — as the point in the medulla oblongata, which Fluorens has designated the vital point — have never been explained, and admit, I imagine, of no explanation, except the change of structure I have now ventured to suggest.

Here, for the moment, my task must end. My object has been to make the scientific reader conversant with what has been said by philosophers upon the subject of sleep and its proximate cause, and to indicate briefly a new line of scientific inquiry. I shall hope, on some future occasion, to be able to announce further and more fruitful labor.

18. Animal Life at Great Depths in the Sea.

MR. GEORGE JEFFREY states that, during the expedition to survey the North Atlantic telegraph line, "there was only one piece of drift-wood met with in the Arctic Sea which showed any marks of having been perforated by marine animals; and this piece of wood has, through the kindness of Sir Leopold McClintock, been submitted to my examination. It had formed part of a fir tree, and was picked up by the Fox on the 13th September, 1860, off the east coast of Greenland, in latitude sixty degrees fifty-four minutes north, longitude forty-one degrees fifty-eight minutes west. It appeared to have been much rubbed and frayed,

probably by attrition against loose or floating ice. On making sections of this piece of wood, I found that the perforations had been caused by a kind of annelid, and that they extended to a considerable depth, although they were of a different nature from the tunnels made by any kind of teredo. Having referred to the account given by the late Sir John Ross, of his Voyage of Discovery to the Arctic Regions, which was published in 1819, I find that in many of the deep-sea soundings, which he so accurately recorded, living 'sea-worms,' or annelids, occurred at depths varying from one hundred and ninety-two to one thousand fathoms.

"The inference I would draw from the fact of animal life existing at great depths in the sea (and which has been lately confirmed by Dr. Wallich), is, that proper precautions ought to be taken to prevent the cable being injured, and the telegraphic action affected, by marine animals of perforating habits. No vegetable substance is free from their attacks; and I have shown, in the case of the Mediterranean line, that the cable, as well as its enclosure of gutta-percha, was pierced, at a depth of between sixty and seventy fathoms, by the xylophaga dorsalis. I think a sheathing of copper, or of any other metal which is not liable to oxidation, would effectually prevent any such injury, and not interfere with the flexibility of the cable.

"I may take this opportunity of remarking, in justice to the memory of the gallant officer to whose explorations I have above referred, that, by means of his 'deep-sea clamm,' he succeeded in taking up and bringing to the surface considerable quantities of stone and mud (as much as six pounds at a time) from the sea-bottom at great depths; and that he says (vol. i. p. 251), on one occasion, 'Soundings were obtained correctly in one thousand fathoms, consisting of soft mud, in which there were worms; and, entangled on the sounding-line, at the depth of eight hundred fathoms, was found a beautiful caput medusæ.' This specimen was described by the late Dr. Leach, in the appendix to Sir John

Ross's work, under the name of Gorgonocephalus Arcticus, and it is still to be seen in the British Museum. It appears to have measured no less than two feet in length, when fully expanded. In the same work Sir John Ross also says (vol. ii. p. 5), 'When the line came up, a small star-fish was found attached to it, below the point marking eight hundred fathoms.' The sea was then a dead calm, and the line became perfectly perpendicular. Animals of a higher degree of organization, such as mollusca and crustacea, were also procured by Sir John Ross, during the same expedition, at rather less depths, in Baffin's Bay. Dr. Wallich was, of course, not aware of his supposed discovery having been thus anticipated more than forty years ago. Sir James Ross's account of his Antarctic voyage of discovery should also be consulted by those who take an interest in this subject, with respect to the results of his deep-sea dredging."

In exploring the great depths of ocean, much had been achieved by America before our *later* expeditions were organized; but much had been long contemplated and earnestly desired by the late Sir Francis Beaufort, who, in 1853, was planning a voyage, in which deep-sounding apparatus, similar to that used lately by Sir Leopold McClintock, was to have been used; but the Russian war interfered. Several voyages used contrivances for obtaining material from the bottom of the ocean; but neither the 'deep-sea clamms,' nor any other instrument, has answered in practice better than a rather modified one, on what is called Brookes's plan. Our author says, —

"The honor of the first attempt to recover specimens of the bottom from great depths belongs to Peter the Great of Russia. That remarkable man and illustrious monarch constructed a deep-sea sounding apparatus especially for the Caspian Sea. It was somewhat in the shape of a pair of ice-hooks, and such as are seen in the hands of the 'ice-man,' as, in his daily rounds, he lifts the blocks of ice from his cart in the street for delivery at the door. It was so contrived

that, when it touched the bottom, the plummet would become detached, and the hook would bring up the specimen."

19. Russian Metallurgical Works.

"IN the year 1700," says Mr. Herbert Barry, "Peter the Great, wishing to develop the mineral resources of his empire, sent two men, named Botachoff and Demidoff, to investigate the facilities which Russia offered for the establishment of iron works. The former went to Nijni Novgorod, and the adjacent governments; the latter to the Oural Mountains. Each of these men established colossal iron works, and handed down a fortune of corresponding magnitude to his ennobled descendants. The mode in which they made money, while at the same time developing the resources of the empire, may be estimated from the statement that cargoes of iron from Botachoff's works used to be floated down the river Oka, and exchanged at Nijni Novgorod, for their own weight of copper money. Russia abounds in iron ore. Numerous deposits of magnetic ore exist in the Oural and Altai, yielding sixty-eight per cent. of iron in the blast furnace. South of Ekaterinberg is found a kidney-red ore, yielding from fifty-five to sixty per cent. The poorest ore in use in Russia is in the government of Viatka, yielding thirty-five per cent. Russian iron is entirely produced by the use of wood charcoal. The waste and ultimate extinction of the numerous forests are now put a stop to by the system of checking off the woods into districts. The time requisite for the growth of timber for fuel is sixty years. The best example known in Russia by Mr. Barry of the mode of mapping out forests is that of the Verkny Sergeefskoi works, in the Central Oural district, where the wood is checked to make eight thousand tons of iron per annum forever, eighty years being allowed for regrowth." — *Athenæum.*

20. Coal as a Reservoir of Power.

BY ROBERT HUNT, F. R. S.

THE sun, according to the philosophy of the day, is the great storehouse of Force. All the grand natural phenomena are directly dependent upon the influence of energies which are poured forth without intermission from the central star of our system. Under the influences of light, heat, actinism, and electricity plants and animals are produced, live, and grow in all their infinite variety. Those physical powers, or, as they were formerly called, those imponderable elements, have their origin in one or other of those mysterious zones which envelop the orb of day, and become evident to us only when mighty cyclones break them up into dark spots. Is it possible to account for the enormous amount of energy which is constantly being developed in the sun? This question may be answered by saying that chemical changes of the most intense activity are discovered to be forever progressing, and that to these changes we owe the development of all the physical powers with which we are acquainted. In our laboratory we establish, by mechanical disturbance, some chemical phenomenon, which becomes evident to our senses by the heat and light which are developed, and we find associated with them the principle which can set up chemical change and promote electrical manifestations. We have produced combustion, say, of a metal, or of a metallic compound, and we have a flame of a color which belongs especially to the substance which is being consumed. We examine a ray of the light produced by that flame by passing it through a prism, and this analysis informs us that colored bands, having a fixed angle of refraction, are constant for that especial metal. Beyond this, re-

search acquaints us with the fact that, if the ray of light is made to pass through the vapor of the substance which gives color to the flame, the lines of the spectrum, which were chromatic, become dark and colorless. We trap a ray of sunlight, and we refract it by means of a spectroscope — an instrument giving results which are already described in this journal — when we detect the same lines as those which we have discovered in our artificial flame. We pursue this very interesting discovery, and we find that several metals which give color to flame, and produce certain lines, when subjected to spectrum analysis, are to be detected in the rays of the sun. Therefore our inference is, that some substances, similar to the terrestrial bodies, with which we are familiar, are actually undergoing a change in the sun, analogous to those changes which we call combustion; and, more than this, we argue that the high probability is, that all solar energies are developed under those conditions of chemical change — that, in fact, the sun is burning, and while solar matter is changing its form, Force is rendered active, and as ray-power passes off into space, as light, heat, &c., to do its work upon distant worlds, and these forms of Force are expended in doing the work of development *on* those worlds. This idea — theory — hypothesis — call it what we may — involves of necessity the waste of energy in the sun, and we must concede the possibility of the blazing sun's gigantic mass becoming eventually a globe of dead ashes, unless we can comprehend some method by which energy can be again restored to the inert matter. Certain it is that the sun has been shining thousands of years, and its influence on this earth we know to have been the production of organized masses, absorbing the radiant energies, in volumes capable of measurement. On this earth, for every equivalent of heat developed, a fixed equivalent of matter has changed its form, and so likewise is it with regard to the other forces. On the sun, in like manner, every cubic mile of sunshine represents the change of form of an equivalent of solar matter, and

that equivalent of matter is no longer capable of supplying Force, unless by some conditions, beyond our grasp at present, it takes up again that which it has lost. That something of this kind must take place is certain. The sun is *not burning out*. After the lapse of thousands of years, we have the most incontrovertible evidence that the light of to-day is no less brilliant now than it was when man walked amidst the groves of Eden. We may venture farther back into the arcana of time, and say that the sun of the past summer has shone with splendor equal to the radiant power which myriads of ages ere yet man appeared on this planet stimulated the growth of those luxuriant forests which perished to form those vast beds from which we derive our coal. Not a ray the less is poured out in any hour of sunshine; not a grain weight of matter is lost from the mass of the sun. If either the sunshine was weakened, or the weight of the vast globe diminished, the planets would vary in their physical conditions, and their orbits would be changed. There is no evidence that either the one or the other has resulted. Let us see if we can guess at any process by which this stability of the solar system is maintained.

It was first shown by Faraday, in a series of experimental investigations which may be regarded as the most beautiful example of inductive science with which the world has been favored since Bacon promulgated his new philosophy, that the quantity of electricity contained in a body was exactly the quantity which was necessary to decompose that body. For example, in a voltaic battery, of zinc and copper plates, a certain fixed quantity of electricity is eliminated by the oxidation of a portion of the zinc. If, to produce this effect, the oxygen of a given measure of water, say a drop, is necessary, the electricity developed will be exactly that which is required to separate the gaseous elements of a drop of water from each other. An equivalent of electricity is developed by the oxidation of an equivalent of zinc, and that electricity is required for the decomposition of an equivalent

of water, or the same quantity of electricity would be equal to the power of effecting the recombination of oxygen and hydrogen into an equivalent of water. The law which has been so perfectly established for electricity is found to be true of the other physical forces. By the combustion, which is a condition of oxidation, of an equivalent of carbon, or of any body susceptible of this change of state, exact volumes of light and heat are liberated. It is theoretically certain that these equivalents of light and heat are exactly the quantities necessary for the formation of the substance from which those energies have been derived. That which takes place in terrestrial phenomena is, it is highly probable, constantly taking place in solar phenomena. Chemical changes, or disturbances analogous to them, of vast energy, are constantly progressing in the sun, and thus is matntained that unceasing outpour of sunshine, which gladdens the earth, and illumines all the planets of our system. Every solar ray is a bundle of powerful forces: light, the luminous life-maintaining energy, giving color to all things; heat, the calorific power which determines the conditions of all terrestrial matter; actinism, peculiarly the force which produces all photographic phenomena; and electricity, regulating the magnetic conditions of this globe. Combined in action, these solar radiations carry out the conditions necessary to animal and vegetable organizations, in all their varieties, and *create* out of a chaotic mass forms of beauty rejoicing in life.

To confine our attention to the one subject before us. Every person knows, that to grow a tree or a shrub healthfully, it must have plenty of sunshine. In the dark we may force a plant to grow, but it forms no woody matter, it acquires no color; even in shade it grows slowly and weak. In sunshine it glows with color, and its frame is strengthened by the deposition of woody matter eliminated from the carbonic acid of the air in which it grows. A momentary digression will make one point here more clear. Men and animals live by consuming the products of the vegetable

world. The process of supporting life by food is essentially one of combustion. The food is burnt in the system, developing that heat which is necessary for life, and the living animal rejects, with every expiration, the combinations, principally carbonic acid, which result from this combustion. This carbonic acid is inhaled by the plant; and, by its vital power, excited by sunshine, it is decomposed; the carbon forms the ligneous structure of the plant, and the oxygen is liberated to renew the healthful condition of the atmosphere. Here we see a sequence of changes analogous to those which have been shown to be a law of electricity.

Every equivalent of matter changing form in the sun sends forth a measured volume of sunshine, charged with the organizing powers as potential energies. These meet with the terrestrial matter, which has the function of living, and they expend themselves in the labor of producing a quantity of wood, which represents the equivalent of matter which has changed form in the sun. The light, heat, chemical and electrical power of the sunshine have produced a certain quantity of wood, and these physical energies have been absorbed, used up, in the production of that quantity. Now, we learn that a cube of wood is the result of a fixed measure of sunshine; common experience teaches us that if we ignite that wood it gives out, in burning, light and heat; while a little examination proves the presence of actinism and electricity in its flame. Philosophy teaches us that the powers set free in the burning of that cube of wood are exactly those which were required for its growth, and that, for the production of it, a definite equivalent of matter changed its form on a globe ninety millions of miles distant from us.

Myriads of ages before man appeared — the monarch of this world — the sun was doing its work. Vast forests grew, as they now grow, especially in the wide-spread swamps of the tropics, and, decaying, gathered into thick mats of humus-like substance. Those who have studied all the conditions of a peat morass will remember how the ligneous matter

loses its woody structure in depth, — depth here representing time, — and how, at the bottom, a bituminous or coaly matter is not unfrequently formed. Some such process as this, continued through long ages, at length produced those extensive beds of coal which are so distinguishingly a feature of the British and American coal-fields. At a period in geological time, when an Old Red Sandstone land was washed by ocean waves highly charged with carbonic acid, in which existed multitudinous animals, whose work in nature was to aid in the building up masses of limestone rock, there prevailed a teeming vegetation from which has been derived all the coal-beds of the British isles. Our space will not allow of any inquiry into the immensity of time required for the growth of the forests necessary for the production of even a single seam of coal. Suffice it to say, that within one coal-field we may discover coal-beds to the depth of six thousand feet from the present surface. The section of such a coal-field will show us coal and sandstone, or shale, alternating again and again, — a yard or two of coal and hundreds of feet of shale, or sandstone, — until we come to the present surface; every one of those deeply-buried coal-beds having been at one time a forest, growing under the full power of a brilliant sun, the result of solar forces, produced then, as now, by chemical phenomena taking place in the sun itself. Every cubic yard of coal in every coal-bed is the result of a very slow, but constant, change of a mass of vegetable matter; that change being analogous to the process of rotting in a large heap of succulent plants. The change has been so slow, and continued under a constantly increasing pressure, that but few of the gaseous constituents have escaped, and nearly all those physical forces which were used in the task of producing the woody matter of the plant, have been held prisoners in the vegetable matter which constitutes coal. How vast, then, must be the store of power which is preserved in the coal deposits of these islands!

We are now raising from our coal-pits nearly one hundred

and ten millions of tons of coal annually. Of this quantity we are exporting to our colonial possessions and foreign parts about ten million tons, reserving nearly a million tons of coal for our home consumption. Not many less than one hundred thousand steam boilers are in constant use in these islands, producing steam to blow the blast for smelting the iron ore, to urge the mills for rolling, crushing, and cutting with giant power, to twirl the spindle, and to urge the shuttle. For every purpose, from rolling cyclopean masses of metal into form to weaving silky textures of the most filmy fineness, steam is used, and this steam is an exact representative of the coal employed, a large allowance being made for the imperfection of human machinery. This requires a little explanation. Coal is a compound of carbon, hydrogen, oxygen, and nitrogen, the last two elements existing in quantities so small, as compared with the carbon, that they may be rejected from our consideration. The heat which we obtain in burning the coal is almost all derived from the carbon; the hydrogen in burning produces some heat, but for our purpose it is sufficient to confine attention to the carbon only.

One pound of pure coal yields, in combining with oxygen in combustion, *theoretically*, an energy equal to the power of lifting 10,808,000 pounds one foot high. The quantity of heat necessary to raise a pound of water one degree will raise 772 pounds one foot. A pound of coal burning should yield 14,000 units of heat, or $772 \times 14{,}000 = 10{,}808{,}000$ pounds, as above. Such is the theoretical value of a pound of pure coal. Many of our coal-seams are about a yard in thickness: several important seams are much thicker than this, and one well-known seam, the thick coal of South Staffordshire, is ten yards in thickness. This, however, concerns us no further than that it is useful in conveying to the mind some idea of the enormous reservoir of power which is buried in our coal formations. One square yard of the coal from a yard-thick seam — that is, in fact, a cubic yard of coal — weighs about 2,240 pounds avoirdupois; the reserved

energy in that cube of coal is equal to lifting 1,729,200 pounds one foot high. We are raising every year about 110,000,000 tons of coal from our coal-beds, each ton of coal being about a square yard. The heat of that coal is equal to a mechanical lifting power which it is scarcely possible to convey to the mind in anything approaching to its reality. If we say it is 190,212,000 millions, we merely state an incomprehensible number. We may do something more than this, if we can convey some idea of the magnitude of the mass of coal which is raised annually in these islands.

The diameter of this globe is 7,926 miles, or 13,880,760 yards; therefore the coal raised in 1870 would make a solid bar, more than eight yards wide and one yard thick, which would pass from east to west through the earth at the equator. Supposing such a mass to be in a state of ignition, we can perhaps imagine the intensity of its heat, and its capability, if employed in converting water into steam, of exerting the vast force which we have endeavored to indicate. It was intimated last year in the House of Commons, by a member of the coal commission, that the decision of that body, after a long and laborious inquiry, would be, that there existed in our coal-fields a supply for about one thousand years at our present rate of consumption. We have, therefore, to multiply the above computation by one thousand to arrive at any idea of the reserved power of our British coal-fields. What must it have been ere yet our coal deposits were disturbed! At the time of the Roman occupation coal was used in this country. In the ruins of Roman Uriconium coal has been found. Certainly up to the present time a quantity of not less than three thousand million tons of coal have been dug out of our carboniferous deposits and consumed. All this enormous mass of matter has been derived from vegetable organizations which have been built up by sunshine. The sun-rays which compelled the plants to grow were used by the plant, absorbed, imprisoned in the cells, and held there as an essential ingredient of the woody mat-

ter. The heat, light, actinism, and electricity, which are developed when we burn a lump of coal, represent exactly the quantity of those forces which were necessary to the growth of the vegetable matter from which that coal was formed. The sunshine of infinitely remote ages becomes the useful power of the present day.

Let it not, however, be supposed that we employ all the heat which is available in our coal. All our appliances, even the very best, are so defective that we lose far more than we use. A pound of pure coal should evaporate thirteen pounds of water; in practice a pound of coal does not evaporate four pounds, even in the most perfectly constructed steam-boilers, with the most complete steam-engines, such as have been constructed for pumping water for the Chelsea, and the other water works upon the Thames.

Numerous attempts have been made to burn our coal so as to secure a more effective result than this. There has been some advance, the most satisfactory being in the regenerative furnace of Mr. Siemens. In this system the solid fuel is converted into crude gas; this gas is mixed with a regulated quantity of atmospheric air, and then burnt. The arrangements are essentially *the gas producer*, or apparatus for converting the fuel bodily into a gaseous state; then there are *the regenerators*. These are sunk chambers, filled with fire bricks, piled in such a manner that a current of air or gas, passing through them, is broken into a great number of parts, and is checked at every step by the interposition of an additional surface of fire brick; four of these chambers are placed below each furnace. The third essential is the *heated chamber*, or furnace proper. This, the furnace chamber, communicates at each extremity with two of the regenerative chambers, and, in directing currents of gas and air upwards through them, the two gaseous streams meet on entering the heated chamber, where they are ignited. The current descends through the remaining two regenerators, and heats the same in such a manner that the uppermost checkerwork

is heated to nearly the temperature of the furnace, whereas the lower portions are heated to a less and less degree, the products of combustion escaping into the chimney comparatively cool. In the course of, say, one hour, the currents are reversed, and the cold air and gas, ascending through the two chambers which have been previously heated, take up the heat there deposited, and enter into combustion at their entrance into the heated chamber, at nearly the temperature at which the products of combustion left the chamber. It is not difficult to conceive that by this arrangement, and with its power of accumulation, any degree of temperature may be obtained in the furnace chamber, without having recourse to purified gas, or to an intensified draught. Where the temperature of the melting chamber has certainly exceeded four thousand degrees of Fahrenheit, the products of combustion escape into the chimney at a temperature of only two hundred and forty degrees. The practical result of this regenerative system is stated to be that a ton of steel requires by the ordinary method about three tons of Durham coke, which, being estimated as coal, will be about four tons, to melt it, whereas, in Siemens's furnace, the melting is effected with twelve hundred weight of ordinary coal. This economy is produced by reserving the heat, by means of the regenerator, which is ordinarily allowed to escape by the chimney.

Another plan for consuming coal with economy has been recently introduced by Mr. T. R. Crampton, and is now in use at the Royal Arsenal, Woolwich, and at the Bowling Iron Works, in Yorkshire. Instead of converting the coal into gas, as in the Siemens process, the coal is reduced by Mr. Crampton to a very fine powder, and then blown into the heated chamber by means of a fan-blast. By this arrangement the perfect combustion of the coal is produced, and a heat of the highest intensity can be obtained. The utilization of this heat, without waste, when it is produced, is an important question still requiring careful attention. There are several other experiments being carried out with a

view to the economical use of coal, but the two to which we have alluded give, up to the present time, the best results. Still, with these we allow more than one half of the heat latent in the coal to escape us. The subtle element eludes our grasp — our charms are powerless to chain the sprite; he will not be bound to labor for us, but passes off into space, regardless of the human Prospero whose wand of science he derides.

In conclusion, our philosophy has enabled us to determine the heat-valve of our coal-fields, and to prove that all this heat has a solar origin. Our science has shown us that, although we can eliminate all this heat, we cannot use it. There is an immense quantity constantly passing into space as radiant heat which we cannot retain.

The circle of action between the vegetable and the animal world is a beautiful and a remarkable provision. The animal burns carbon, and sends into the air carbonic acid (a compound of carbon and oxygen), the vegetable breathes that carbonic acid, and decomposes it; the carbon is retained, and the oxygen liberated in purity, to maintain the life and fire-supporting principle of the atmosphere. Changes similar to these may be constantly going forward in the sun, and producing those radiations which are poured forth in volumes, far beyond the requirements of all the planets of our system. Although there is, probably, some circle of action analogous to that which exists upon this earth, maintaining the permanency of the vegetable and animal world, still there must be a waste of energy, which must be resupplied to the sun.

May it not be that Sir Isaac Newton's idea, that the comets traversing space gather up the waste heat of the solar system, and eventually, falling into the sun, restore its power, is nearer the truth than the more modern hypothesis that meteorites are incessantly raining an iron shower upon the solar surface, and by their mechanical impact reproducing the energy as constantly as it is expended?

21. Hot Springs of New Zealand.

LIEUTENANT the Honorable H. Meade, in his very interesting work, A Ride through the Disturbed Districts of New Zealand, tells us that he and his party had not journeyed far inland before they came to the remarkable region of hot springs and geysers. A strange existence is that of the inhabitants of Ohinemutu, dreaming, or, rather, bathing, away their days in their village, built on what is nothing more than the thin crust of a vast boiler. Hot springs hiss and seethe in every direction, and, except during a southerly wind, the natives live in a perpetual steam cloud. Steam jets spurt from innumerable cracks and crevices; here the hot water spouts and boils furiously, there it lies in still pools of an agreeable warmth. The village cooking is all done by nature; food wrapped in flaxen baskets is hung in the pools, and boils beautifully; or, by scraping a hole in the ground, placing the dish and covering it up, a dinner is soon steamed or stewed. Every few minutes the great geyser silenced all other voices as it rushed upwards, and rose in one grand bouquet of forty or fifty feet in height. For a few seconds it maintained this level, its feathery spray flashing in the moonbeams; then, slowly sinking into the cavern whence it rose, it died away in a boiling surf, from which huge banks of steam rolled silently up the dark hill-side. The whole population takes to the water of the lake at a certain hour every evening, the temperature being that of an ordinary warm bath, except at places which are known and avoided, where the boiling water bubbles from the bottom. There are instances on record of horses and, worse still, of poor little native children, being boiled alive in the caldrons. The chemical deposits of this geological formation produce the most beautiful effects. The water of some of the basins is

colored emerald green; close by are others of a brilliant turquoise, a cobalt blue, or a pink, and all perfectly clear and transparent. By the brink of the springs grow rare and beautiful ferns; owing to the steamy atmosphere, these, as well as other plants, are of a singularly delicate and brilliant tint of green. Let those who know only the normal aspects of nature endeavor, if they can, to see Te Tarata, the great "ngahwa," or hot spring.

From the mouth of the crater the wide-spreading waters fall in thousands of cascades, from terrace to terrace of crystallized basins. The water from each successive pool escapes in little curving jets, to fill more numerous and broader pools below, or falls in a curtain of glittering drops from the fringes of crystals and glassy stalactites, which form the margins of all the basins and terraces, and finally flows into Rotomahana, over a smooth, hard flooring of a semi-transparent, white-glazed surface, which paves the shores of the lake for a considerable distance. The water in the several basins is of the same deep blue as at the source; but the crystal margins, as well as the delicate crystallized tracery (reminding one of lace in high relief), which covers the whole of the broad flight of steps and curving terraces, are as white as driven snow, save in a few places, where, as if for the sake of contrast, a delicate pink hue is introduced. In shape most of the terraces somewhat resemble the curved battlements of ancient castles, though not so lofty; and the margins of the pools which they contain are disposed in almost symmetrical curves, each of whose extremities rests on the swell of those adjoining.

22. Atoms.

A Lecture by PROFESSOR CLIFFORD, M. A., *delivered in Manchester, England, November* 20, 1872.

IF I were to wet my finger, and then rub it along the edge of this tumbler, I should, no doubt, persuade the glass to give out a certain musical note. So, also, if I were to sing to that glass the same note loud enough, I should get the glass to answer me back with a note.

I want you to remember that fact, because it is of capital importance for the arguments we shall have to consider to-night. The very same note which I can get the tumbler to give out by agitating it, by rubbing the edge, that same note I can also get the tumbler to answer back to me when I sing to it. Now, remembering that, please to conceive a rather complicated thing that I am now going to try to describe to you. The same property that belongs to the glass belongs also to a bell which is made out of metal. If that bell is agitated by being struck, or in any other way, it will give out the same sound that it will answer back if you sing that sound to it; but if you sing a different sound to it then it will not answer.

Now, suppose that I have several of these metal bells which answer to quite different notes, and that they are all fastened to a set of elastic stalks, which spring out of a certain centre to which they are fastened. All these bells, then, are not only fastened to these stalks, but they are held there in such a way that they can spin round upon the points to which they are fastened.

And then the centre, to which these elastic stalks are fastened or suspended, you may imagine as able to move in all manner of directions, and that the whole structure, made up

of these bells, and stalks, and centre, is able to spin round any axis whatever. We must also suppose that there is surrounding this structure a certain framework. We will suppose the framework to be made of some elastic material, so that it is able to be pressed in to a certain extent. Suppose that framework is made of whalebone, if you like. Now, this structure I am going, for the present, to call an "atom." I do not mean to say that atoms are made of a structure like that. I do not mean to say that there is anything in an atom which is in the shape of a bell, and I do not mean to say that there is anything analogous to an elastic stalk in it. But what I mean is this,—that an atom is something that is capable of vibrating at certain definite rates; also that it is capable of other motions of its parts besides those vibrations at certain definite rates; and also that it is capable of spinning round about any axis. Now, by the framework which I suppose to be put round that structure, made out of bells and elastic stalks, I mean this, that supposing you had two such structures, then you cannot put them closer together than a certain distance, but they will begin to resist being put close together after you have put them as near as that, and they will push each other away if you attempt to put them closer. That is all I mean then. You must only suppose that that structure is described, and that set of ideas is put together, just for the sake of giving us some definite notion of a thing which has similar properties to that structure. But you must not suppose that there is any special part of an atom which has got a bell-like form, or any part like an elastic stalk made out of whalebone.

Now, having got the idea of such a complicated structure, which is capable, as we said, of vibratory motion, and of other sorts of motion, I am going on to explain what is the belief of those people who have studied the subject about the composition of the air which fills this room. The air which fills this room is what is called a gas; but it is not a simple gas; it is a mixture of two different gases, oxygen

and nitrogen. Now, what is believed about this air is, that it consists of quite distinct portions, or little masses of air, that is, of little masses each of which is either oxygen or nitrogen, and that these little masses are perpetually flying about in all directions. The number of them in this room is so great that it strains the powers of our numerical system to count them. They are flying about in all directions, and mostly in straight lines, except where they get quite near to one another, and then they rebound, and fly off in other directions. Part of these little masses which compose the air are of one sort; they are called oxygen. All those little masses which are called oxygen are alike; they are of the same weight, they have the same rates of vibration, and they go about on the average at a certain rate. The other part of these little masses is called nitrogen, and they have a different weight; but the weight of all the nitrogen masses is the same, as nearly as we can make out. They have again the same rates of vibration; but the rates of vibration that belong to them are different from the rates of vibration that belong to the oxygen masses; and the nitrogen masses go about on the average at a certain rate, but this rate is different from the average rate at which the oxygen masses go about. So, then, taking up that structure, which I endeavored to describe to you at first, we should represent the state of the air in this room as being made up of such a lot of compound atoms of those structures of bells and stalks, with frameworks round them, that I described to you, being thrown about in all directions with great rapidity, and continually impinging against one another, each flying off in a different direction, so that they would go mostly in straight lines (you must suppose them for a moment not to fall down towards the earth), excepting where they come near enough for their two frameworks to be in contact, and then their frameworks throw them off in different directions: that is a conception of the state of things which actually takes place inside of gas.

Now, the conception which scientific men have of the state of things which takes place inside of a liquid is different from that. We should conceive it in this way: We should suppose that a number of these structures are put so close together that their frameworks are always in contact; and yet they are moving about, and rolling among one another, so that no one of them keeps the same place for two instants together, and any one of them is travelling all over the whole space. Inside of this glass, where there is a liquid, all the small particles or molecules are running about among one another, and yet none of them goes for any appreciable portion of its path in a straight line, because there is no small distance that it goes without being in contact with others all around it; and the effect of this contact of the others all around it is, that they press against it, and force it out of a straight path. So that the path of a particle in a liquid is a sort of wavy path; it goes in and out in all directions, and a particle at one part of the liquid will, at a certain time, have traversed all the different parts, one after another.

The conception of what happens inside of a solid body, say a crystal of salt, is different again from this. It is supposed that the very small particles which constitute that crystal of salt do not travel about from one part of the crystal to another, but that each one of them remains pretty much in the same place. I say "pretty much," but not exactly, and the motion of it is like this: Suppose one of my structures, with its framework round it, to be fastened up by elastic strings, so that one string goes to the ceiling, and another to the floor, and another to each wall, so that it is fastened by all these strings. Then if these strings are stretched, and a particle is displaced in any way, it will just oscillate about its mean position, and will not go far away from it; and if forced away from that position, it will come back again. That is the sort of motion that belongs to a particle in the inside of a solid body. A solid body, such as a crys-

tal of salt, is made up, just as a liquid or a gas is made up, of innumerable small particles, but they are so attached to one another that each of them can only oscillate about its mean position. It is very probable that it is also able to spin about any axis in that position or near it; but it is not able to leave that position finally, and to go and take up another position in the crystal; it must stop in or near about the same position.

These, then, are the views which are held by scientific men at present about what actually goes on inside of a gaseous body, or a liquid body, or a solid body. In each case the body is supposed to be made up of a very large number of very small particles; but in one case these particles are very seldom in contact with one another, that is, very seldom within range of each other's action; in this case they are, during the greater part of the time, moving separately along straight lines. In the case of a liquid, they are constantly within the range of each other's action, but they do not move along straight lines for any appreciable part of the time; they are always changing their position relatively to the other particles, and one of them gets about from one part of the liquid to another. In the case of a solid they are always also within the range of each other's action, and they are so much within that range that they are not able to change their relative positions; and each one of them is obliged to remain in very nearly the same position.

Now what I want to do this evening is to explain to you, so far as I can, the reasons which have led scientific men to adopt these views; and what I wish especially to impress upon you is this, that what is called the "atomic theory," that is, what I have just been explaining, is no longer in the position of a theory, but that such of the facts as I have just explained to you are really things which are definitely known, and which are no longer suppositions; that the arguments by which scientific men have been led to adopt these views are such as, to anybody who fairly considers them,

justify that person in believing that the statements are true. Now, first of all, I want to explain what the reasons are why we believe that the air consists of separate portions, and that these portions are repetitions of the same structures; that is to say, that in the air we have two structures really, each of them a great number of times repeated. Take a simple illustration, which is a rather easier one to consider. Suppose we take a vessel which is filled with oxygen. I want to show what the reasons are which lead us to believe that that gas consists of a certain structure, which is a great number of times repeated, and that between two examples of that structure, which exist inside of the vessel, there is a certain empty space which does not contain any oxygen. That oxygen gas contained in the vessel is made up of small particles which are not close together, and each of these particles has a certain structure, which structure also belongs to the rest of the particles. Now this argument is rather a difficult one, and I shall ask you, therefore, to follow it as closely as possible, because it is an extremely complicated argument to follow out the first time that it is presented to you.

I want to consider again the case of this finger-glass. You must often have tried that experiment — that a glass will give out, when it is agitated, the same note which it will return when it is sung to. Well, now, suppose that I have got this room filled with a certain number of such atomic structures as I have endeavored to describe, that is to say, of sets of bells, the bells answering to certain given notes. Each of these little structures is exactly alike, that is to say, it contains just the bells corresponding to the same notes. Well, now, suppose that you sing to a glass or to a bell, there are three things that may happen. First, you may sing a note which does not belong to the bell at all. In that case the bell will not answer; it will not be affected or agitated by your singing that note, but it will remain quite still. Next, if you sing a note that belongs to the bell, but if you

sing it rather low, then the effect of that note will be to make the bell move a little, but the bell will not move so much as to give back the note in an audible form. Thirdly, if you sing the note which belongs to the bell loud enough, then you will so far agitate the bell that it will give back the note to you again. Now, exactly that same property belongs to a stretched string, or the string of a piano. You know that if you sing a certain note in a room where there is a piano, the string belonging to that note will answer you, if you sing loud enough. The other strings will not answer at all. If you do not sing loud enough, the string will be affected, but not enough to answer you. Now let us imagine a screen of piano strings, all of exactly the same length, of the same material, and stretched equally, and that this screen of strings is put across the room; that I am at one end, and that you are at another, and that I proceed to sing notes straight up the scale. Now, while I sing notes which are different from that note which belongs to the screen of strings, they will pass through the screen without being altered, because the agitation of the air which I produce will not affect the strings. But that note will be heard quite well at the other side of the screen. You must remember that when the air carries a sound, it vibrates at a certain rate belonging to the sound. I make the air vibrate by singing a particular note, and if that rate of vibration corresponds to the strings, the air will pass on part of its vibration to the strings, and so make the strings move. But if the rate of vibration is not the one that corresponds to the strings, then the air will not pass on any of its vibrations to the strings, and consequently the sound will be heard equally loud after it has passed through the strings. Having put the strings of the piano across the room, if I sing up the scale, when I come to the note which belongs to each of the strings, my voice will suddenly appear to be deadened, because at the moment that the rate of vibration which I impress upon the air coincides with that belonging to the strings, part of it

will be taken up in setting the strings in motion. As I pass the note, then, which belongs to the strings, that note will be deadened.

Instead of a screen of piano strings, let us put in a series of sets of bells, three or four belonging to each set, so that each set of bells answers to three or four notes, and so that all the sets are exactly alike. Now, suppose that these sets of bells are distributed all over the middle part of the room, and that I sing straight up the scale, from one note to another, until I come to the note that corresponds to one of the bells in these sets, then that note will appear to be deadened at the other end, because part of the vibration communicated to the air will be taken up in setting those bells in motion. When I come to another note which belongs to them, that note will also be deadened; so that a person listening at the other end of the room would observe that certain notes were deadened, or even had disappeared altogether. If, however, I sing loud enough, then I should set all these bells vibrating. What would be heard at the other end of the room? Why, just the chord compounded out of those sounds that belonged to the bells, because the bells, having been set vibrating, would give out the corresponding notes. So, you see, there are here three facts: When I sing a note which does not belong to the bells, my voice passes to the end of the room without diminution. When I sing a note that does belong to the bells, then, if it is not loud enough, it is deadened by passing through the screen; but if it is loud enough, it sets the bells vibrating, and is heard afterwards. Now just notice this consequence: We have supposed a screen made out of these structures that I have imagined to represent atoms, and when I sing through the scale at one end of the room, certain notes appear to be deadened. If I take away half of those structures, what will be the effect? Exactly the same notes will be deadened, but they will not be deadened so much; the notes which are picked out of the thinner screen to be deadened will be exactly the same

notes, but the amount of the deadening will not be the same.

So far we have only been talking about the transmission of *sound.* You know that sound consists of certain waves which are passed along in the air; they are called "aerial vibrations." Now, we also know that light consists of certain waves, which are passed along, not in the air, but along another medium. I cannot stop at present to explain to you what the sort of evidence is upon which that assertion rests, but it is the same sort of evidence as that which I shall try to show you belongs to the statement about atoms, that is to say, the "undulatory theory," as it is called, of light. The theory that light consists of waves transmitted along a certain medium has passed out of the stage of being a theory, and has passed into the stage of being a demonstrated fact. The difference between a theory and a demonstrated fact is something like this: If you supposed a man to have walked from Chorlton Town Hall down here, say in ten minutes, the natural conclusion would be that he had walked along the Stretford Road. Now, that theory would entirely account for all the facts, but at the same time the facts would not be proved by it. But suppose it happened to be winter time, with snow on the road, and that you could trace the man's footsteps all along the road, then you would know that he had walked along that way. Now, the sort of evidence we have to show that light does consist of waves transmitted through a medium is the sort of evidence that footsteps upon the snow make; it is not a theory merely which simply accounts for the facts, but it is a theory which can be reasoned back to from the facts without any other theory being possible. So that you must just for the present take it for granted that the arguments in favor of the hypothesis that light consists of waves are such as to take it out of the region of hypothesis, and make it into demonstrated fact.

Very well, then, light consists of waves transmitted along

this medium in the same way that sound is transmitted along the air. The waves are not of the same kind, but still they are waves, and they are transmitted as such, and the different colors of light correspond to the different lengths of these waves, or to the different rates of the vibration of the medium, just as the different pitches of sound correspond to the different lengths of the air-waves, or to the different rates of the vibration of the air, Now, if we take any gas, such as oxygen, and we pass light through it, we find that that gas intercepts, or weakens, certain particular colors. If we take any other gas, such as hydrogen, and pass light through it, we find that that gas intercepts, or weakens, certain other particular colors of the light. Now, there are two ways in which it can do that. It is clear that the undulations, or waves, are made weaker, because they happen to coincide with the rate of vibration of the gas they are passing through. But the gas may vibrate, as a whole, in the same way that the air does when you transmit sound. Or the waves may be stopped, because the gas consists of a number of small structures, just as my screen, which I imagine to consist of structures, or just as the screen of piano strings is made up of the same structure many times repeated. Either of these suppositions would apparently, at first, account for the fact that certain waves of light are intercepted by the gas, while others are let through. But now how is it that we can show one of these suppositions is wrong and the other is right? Instead of taking so small a structure as piano-strings, let us suppose we had got a series of fiddles, the strings of all of them being stretched exactly in tune. I suppose this case because it makes a more complicated structure, for there would be two or three notes corresponding in each fiddle. If you suppose this screen of fiddles to be hung up, and then compressed, what will be the effect? The effect of the compression will be, if they are all in contact, that each fiddle itself will be altered. If the fiddles are compressed longways, the strings will give

lower notes than before, and consequently the series of notes which will be intercepted by that screen will be different from the series of notes which were intercepted before. But if you have a screen made out of fiddles, which are at a distance from one another, and then if you compress them into a smaller space by merely bringing them nearer together, without making them touch, then it is clear that exactly the same notes will be intercepted as before, only, as there will be more fiddles in the same space, the deadening of the sound will be greater.

Now, when you compress any gas, you find that it intercepts exactly the same colors of light which it intercepted before it was compressed. It follows, therefore, that the rates of vibration which it intercepts depend not upon the mass of the gas whose properties are altered by the compression, but upon some individual parts of it, which were at a distance from one another before, and which are only brought nearer together without being absolutely brought into contact so as to squeeze them. That is the sort of reasoning by which it is made clear that the interception of light, or particular waves of light by means of a gas, must depend on certain individual structures in the gas, which are at a distance from one another, and which, by compression, are not themselves compressed, but only brought nearer to one another.

There is an extremely interesting consequence which follows from this reasoning, and which was deduced from it by Professor Stokes, in the year 1851, and which was afterwards presented in a more developed form in the magnificent researches of Kirchhoff, namely, the reasoning about the presence of certain matter in the sun. If you analyze the solar light by passing it through a prism, the effect of the prism is to divide it off, so as to separate the light into the different colors which it contains. That line of variously-colored light which is produced by the prism, is, as you know, called the spectrum. Now, when that spectrum is

made in a very accurate way, so that the parts of it are well defined, it is observed to contain certain dark lines, that is, there is a certain kind of light which is missing in the sunlight; certain kinds of light, as we travel along the scale of lights, are missing. Why are they missing? Because there is something that the light has passed through which intercepts or weakens those kinds of light. Now that something which the light has passed through, how shall we find out what it is? It ought to be the same sort of substance which, if it were heated, would give out exactly that kind of light. Now there is a certain kind of light which is intercepted which makes a group of dark lines in the solar spectrum. There are two principal lines, which together are called the line D; and it is found that exactly that sort of light is emitted by sodium when heated hot enough. The conclusion, therefore, is, that that matter which intercepts that particular part of the solar light is sodium, or that there is sodium somewhere between us and the hot portion of the sun which sends us the light. And other reasons lead us to conclude that this sodium is not in the atmosphere of the earth, but in the neighborhood of the sun; that it exists in a gaseous state in the sun's atmosphere. And nearly all the lines in the solar spectrum have been explained in that way, and shown to belong to certain substances which we are able to heat here, and to show that when they are heated they give out exactly the same kind of light which they intercepted when the light was first given out by the sun and they stood in the way. So, you see, that is a phenomenon exactly like the phenomenon presented by the finger-glass that we began with.

Precisely the same light which any gas will give out when it is heated, that same kind of light it will stop, or much weaken it, if the light is attempted to be passed through it. That means that this medium which transmits light, and which we call the "luminiferous ether," has a certain rate of vibration for every particular color of the spectrum. When that

rate of vibration coincides with one of the rates of vibration of an atom, then it will be stopped by that atom, because it will set the atom vibrating itself. If, therefore, you pass light of any particular color through a gas, whose atoms are capable of the corresponding rate of vibration, the light will be cut off by the gas. If, on the other hand, you so far heat the gas that the atoms are vibrating strongly enough to give out light, it will give out a light of a kind which it previously stopped.

We have reason, then, for believing that a simple gas consists of a great number of atoms; that it consists of very small portions, each of which has a complicated structure, but that structure is the same for each of them, and that these portions are separate, or that there is space between them.

In the next place, I want to show you what is the evidence upon which we believe that these portions of the gas are in motion — that they are constantly moving.

If this were a political instead of a scientific meeting, there would, probably, be some people who would be inclined to disagree with us, instead of all being inclined to agree with one another; and these people might have taken it into their heads, as has been done in certain cases, to stop the meeting by putting a bottle of sulphuretted hydrogen in one corner of the room and taking the cork out. You know that, after a certain time, the whole room would contain sulphuretted hydrogen, which is a very unpleasant thing to come in contact with. Now, how is it that that gas which was contained in a small bottle could get in a short time over the whole room unless it was in motion? What we mean by motion is change of place. Now, the gas was in one corner, and it is afterwards all over the room. There has, therefore, been motion somewhere, and this motion must have been of considerable rapidity, because we know that there was the air which filled the room beforehand to oppose resistance to that motion. We cannot suppose that the sul-

phuretted hydrogen gas was the only thing that was in motion, and that the air was not in motion itself, because, if we had used any other gas, we should find that it would diffuse itself in exactly the same way. Now, an argument just like that applies also to the case of a liquid. Suppose this room were a large tank entirely filled with water, and anybody were to drop a little iodine into it, after a certain time the whole of the water would be found to be tinged of a blue color. Now that drop may be introduced into any part of the tank you like, either at the top or bottom, and it will always diffuse itself over the whole water. There has here again been motion. We cannot suppose that the drop which was introduced was the only thing that moved about, because any other substance would equally have moved about. And the water has moved into the place where the drop was, because in the place where you put the drop there is not so much iodine as there was to begin with. Well, then, it is clear that in the case of a gas these particles, of which we have shown it to consist, must be constantly in motion, and we have shown also that a liquid must consist of parts that are in motion, because it is able to admit the particles of another body among them.

Now, when we have decided that the particles of a gas are in motion, there are two things that they may do: they may either hit against one another, or they may not. Now, it is established that they do not hit against one another, and that they do not proceed along straight lines independent of one another. But I cannot at present explain to you the whole of the reasoning upon which that conclusion is grounded. It is grounded upon some rather hard mathematics. It was shown by Professor Clerk Maxwell that a gas cannot be a medium consisting of small particles, moved about in all directions in straight lines, which do not interfere with one another, but which bound off from the surfaces which contain this medium. Supposing we had a box containing a gas of this sort. Well, these particles do not interfere with

one another, but only rebound when they come against the sides of the box; then that portion of the gas will behave, not like a gas, but like a solid body. The peculiarity of liquids and gases is, that they do not mind being bent, and having their shape altered. It has been shown by Clerk Maxwell that a medium, whose particles do not interfere with one another, would behave like a solid body, and object to be bent. It was a most extraordinary conclusion to come to, but it is entirely borne out by the mathematical formulæ. It is certain that, if there were a medium composed of small particles flying about in all directions, and not interfering with one another, then that medium would be to a certain extent solid, that is, would resist any bending or change of shape. By that means, then, it is known that these particles do run against one another. Now, they come apart again. There were two things, of course, they might do: they might either go on in contact, or they might come apart. Now, we know that they come apart for this reason: We have already considered how two gases in contact will diffuse into one another. If you were to put a bucket containing carbonic acid (which is very heavy) upon the floor of this room, it would, after a certain time, diffuse itself over all the room; you would find carbonic acid gas in every part of the room. Now, Graham found that if you were to cover over the top of that bucket with a very thin cover made out of graphite, or black lead, then the gas would diffuse itself over the room pretty nearly as fast as before. The graphite acts like a porous body, as a sponge does to water, and lets the gas get through. The remarkable thing is, that if the graphite is thin, the gas will get through nearly as fast as it will if nothing is put between to stop it. Graham found out another fact. Suppose that bucket to contain two very different gases, say a mixture of hydrogen and carbonic acid gas. Then the hydrogen would come out through the black lead very much faster than the carbonic acid gas. Now, it is found by mathematical calculation that if you have two

gases, which are supposed to consist of small particles which are all banging about, the gas whose particles are lightest will come out quickest; that a gas which is four times as light will come out twice as fast; and a gas nine times as light will come out three times as fast, and so on. Consequently, when you mix two gases together, and then pass them through a thin piece of black lead, the lightest gas comes out quickest, and is, as it were, sifted from the other. Now, suppose we put pure hydrogen into a bucket, and put black lead on the top, and then see how fast the hydrogen comes out. If the particles of the hydrogen are different from one another, if some are heavier, the lighter ones will come out first. Now, let us suppose we have got a vessel, which is divided into two parts by a thin wall of black lead. We will put hydrogen into one of these parts, and allow it to come through this black lead into the other part; then if the hydrogen contains any molecules or atoms which are lighter than the others, those will come through first. If we test the hydrogen that has come through, we shall find that the atoms, as a rule, on one side of this wall are lighter than the atoms on the other side. How should we find that out? Why, we should take these two portions of gas, and we should try whether one of them would pass through another piece of black lead quicker than the other, because, if it did, it would consist of lighter particles. Graham found that it did not pass any quicker. Supposing you put hydrogen into one half of such a vessel, and then allow the gas to diffuse itself through the black lead, the gas on the two sides would be found to be of precisely the same qualities. Consequently there has not been in this case any sifting of the lighter particles from the heavier ones, and consequently there could not have been any lighter particles to sift, because we know that if there were any they would have come through quicker than the others. Therefore we are led to the conclusion that in any simple gas, such as hydrogen or oxygen, all the atoms are, as nearly as possible, of the same weight. We have no

right to conclude that they are exactly of the same weight, because there is no experiment in the world that enables us to come to an exact conclusion of that sort. But we are enabled to conclude that, within the limits of experiment, all the atoms of a simple gas are of the same weight. What follows from that? It follows that when they bang against one another, they must come apart again; for if two of them were to go on as one, that one would be twice as heavy as the others, and would consequently be sifted back. It follows, therefore, that two particles of a gas which bang against one another must come apart again, because, if they were to cling together, they would form a particle twice as heavy, and so this clinging would show itself when the gas was passed through the screen of black lead.

Now, there are certain particles or small masses of matter which we know to bang against one another, according to certain laws, such, for example, as billiard-balls. Now, the way in which different bodies, after hitting together, come apart again, depends on the constitution of those bodies. The earlier hypothesis about the constitution of a gas supposed that the particles of them came apart according to the same law that billiard-balls do; but that hypothesis, although it was found to explain a great number of phenomena, did not explain them all. And it was Professor Clerk Maxwell again who found the hypothesis which does explain all the rest of the phenomena. He found that particles, when they come together, separate as if they repelled one another, or pushed one another away, and as if they did that much more strongly when close together than when farther apart. You know that what is called the great law of gravitation asserts that all bodies pull one another together, according to a certain law, and that they pull one another more when close than when farther apart. Now that law differs from the law which Clerk Maxwell found out as affecting the repulsion of gaseous particles. The law of attraction of gravitation is this: that when you halve the distance, you have to multiply

the attraction four times — twice two make four. If you divide the distance into three, you must multiply the attraction nine times — three times three are nine. Now, in the case of atomic repulsion, you have got to multiply, not twice two, or three times three, but five twos together, which multiplied make thirty-two. If you halve the distance between two particles, you increase the repulsion thirty-two times. So also five threes multiplied together make two hundred and forty-three; and if you divide the distance between two particles by three, then you increase the repulsion by two hundred and forty-three. So, you see, the repulsion increases with enormous rapidity as the distance diminishes. That law is expressed by saying that the repulsion of two gases is inversely as the fifth power of the distance. But now I must warn you against supposing that that law is established in the same sense that these other statements that we have been making are established. That law is true, provided that there is a repulsion between two gaseous particles, and that it varies as a power of the distance; it is proved that if there is any law of repulsion, and if the law is that it varies as some power of the distance, then that power cannot be any other than the fifth. It has not been shown that the action between the two particles is not something perhaps more complicated than this, but which, on the average, produces the same results. But still the statement that the action of gaseous molecules upon one another can be entirely explained by the assumption of a law like that is the newest statement in physics since the law of gravitation was discovered. You know that there are other actions of matter, which apparently take place through intervening spaces, and which always follow the same law as gravitation, such as the attraction or repulsion of magnetical or electrical particles; those follow the same law as gravitation. But here is a law of repulsion which follows a different law to that of gravitation, and in that lies the extreme interest of Professor Clerk Maxwell's investigation.

Now, the next thing that I want to give you reasoning for is again rather a hard thing in respect of the reasoning, but the fact is an extremely simple and beautiful one. It is this: Suppose I have two vessels, say cylinders, with stoppers which do not fit upon the top of the vessel, but slide up and down inside, and yet fit exactly. These two vessels are of exactly the same size; one of them contains hydrogen, and the other contains oxygen. They are to be of the same temperature and pressure, that is to say, they will bear exactly the same weight on the top. Very well, these two vessels, having equal volumes of gas of the same pressure and temperature, will contain just the same number of atoms in each, only the atoms of oxygen will be heavier than the atoms of hydrogen. Now, how is it that we arrive at that result? I shall endeavor to explain the process of reasoning. Boyle discovered a law about the dependence of the pressure of a gas upon its volume, which showed that if you squeezed a gas into a smaller space, it will press so much the more as the space has been diminished. If the space has been diminished one half, then the pressure is doubled; if the space is diminished to one third, then the pressure is increased to three times what it was before. This holds for a varying volume of the same gas. That same law would tell us that if we put twice the quantity of gas into the same space, we should get twice the amount of pressure. Now Dalton made a new statement of that law, which expresses it in this form: That when you put more gas into a vessel, which already contains gas, the pressure that you get is the sum of the two pressures which would be got from the two gases separately. You will see directly that that is equivalent to the other law. But the importance of Dalton's statement of the law is this, that it enabled the law to be extended from the case of the same gas to the case of two different gases. If, instead of putting a pint of oxygen into a vessel already containing a pint, I were to put in a pint of nitrogen, I should equally get a double pressure. The

oxygen and nitrogen, when mixed together, would exert the sum of the pressures upon the vessel that the oxygen and nitrogen would exert separately. Now, the explanation of that pressure is this: The pressure of the gas upon the sides of the vessel is due to the impact of these small particles, which are constantly flying about, and impinging upon the sides of the vessel. It is, first of all, shown mathematically that the effect of that impinging would be the same as the pressure of the gas. But the amount of the pressure could be found if we knew how many particles there were in a given space, and what was the effect of each one when it impinged on the sides of the vessel. You see directly why it is that putting twice as many particles, which are going at the same rate, into the same vessel, we should get twice the effect. Although there are just twice as many particles to hit the sides of the vessel, they are apparently stopped by each other when they bound off. But the effect of there being more particles is to make them come back quicker; so that altogether the number of impacts upon the sides of the vessel is just doubled when you double the number of particles. Now, supposing we have got a cubic inch of space, then the amount of pressure upon the side of that cubic inch depends upon the number of particles inside the cube, and upon the energy with which each one of them strikes against the sides of the vessel.

Well, now, again, there is a law which connects together the pressure of a gas and its temperature. It is found that there is a certain absolute zero of temperature, and that if you reckon your temperature from that, then the pressure of the gas is directly proportional to the temperature; that twice the temperature will give twice the pressure of the same gas, and three times the temperature will give three times the pressure of the same gas.

Well, now, we have just got to remember these two rules: the law of Boyle, as expressed by Dalton, connecting together the pressure of a gas and its volume, and this law

which connects together the pressure with the absolute temperature. You must remember that it has been calculated by mathematics that the pressure upon one side of a vessel of a cubic inch has been got by multiplying together the number of particles into the energy with which each of them strikes against the side of the vessel. Now, if we keep that same gas in a vessel, and alter its temperature, then we find that the pressure is proportional to the temperature; but since the number of molecules remains the same when we double the pressure, we must alter that other factor in the pressure, we must double the energy with which each of the particles attacks the side of the vessel; that is to say, when we double the temperature of the gas, we double the energy of each particle; consequently the temperature of the gas is proportional always to the energy of its particles. That is the case with a single gas. If we mix two gases, what happens? They come to exactly the same temperature. It is calculated also by mathematics that the particles of one gas have the same effect as those of the other; that is, the light particles go faster to make up for their want of weight. If you mix oxygen and hydrogen, you find that the particles of hydrogen go four times as fast as the particles of oxygen. Now, we have here a mathematical statement, that, when two gases are mixed together, the energy of the two particles is the same, and with any one gas considered by itself that energy is proportional to the temperature. Also, when two gases are mixed together, the two temperatures become equal. If you think over that a little, you will see that it proves that, whether we take the same gases or different gases, the energy of the single particles is always proportional to the temperature of the gas.

Well, now, what follows? If I have two vessels containing gas at the same pressure and the same temperature (suppose that hydrogen is in one and oxygen in the other), then I know that the temperature of the hydrogen is the same as the temperature of the oxygen, and that the pressure of the hydro-

gen is the same as the pressure of the oxygen. I also know (because the temperatures are equal) that the average energy of a particle of the hydrogen is the same as that of a particle of the oxygen. Now, the pressure is made up by multiplying the energy by the number of particles in both gases, and, as the pressure in both cases is the same, therefore the number of particles is the same. That is the reasoning. I am afraid it will seem rather complicated at first hearing, but it is this sort of reasoning which establishes the fact that, in two equal volumes of different gases at the same temperature and pressure, the number of particles is the same.

Now, there is an exceedingly interesting conclusion which was arrived at very early in the theory of gases, and calculated by Mr. Joule. It is found that the pressure of a gas upon the sides of a vessel may be represented quite fairly in this way: Let us divide the particles of gas into three companies or bands. Suppose I have a cubical vessel in which one of these companies is to go forward and backward, another right and left, and the other to go up and down. If we make those three companies of particles to go in their several directions, then the effect upon the sides of the vessel will not be altered; there will be the same impact and pressure. It was also found out that the effect of this pressure would not be altered if we combined together all the particles forming one company into one mass, and made them impinge with the same velocity upon the sides of the vessel. The effect of the pressure would be just the same. Now, we know what the weight of a gas is, and we know what the pressure is that it produces, and we want to find the velocity it is moving at on the average. We can find out at what velocity a certain weight has got to move in order to produce a certain definite impact. Therefore we have merely got to take the weight of the gas, divide it by three, and to find how fast that has got to move in order to produce the pressure, and that will give us the average rate at which the gas is moving. By that means Mr. Joule calculated that, in

air of ordinary temperature and pressure, the velocity is about five hundred metres per second, nearly five miles in sixteen seconds, or nearly twenty miles a minute — about sixty times the rate of an ordinary train.

The average velocity of the particles of gas is about one and a half times as great as the velocity of sound. Now, you can easily remember the velocity of sound in air at freezing point; it is three hundred and thirty-three metres per second; so that about one and a half times, really 1.432, of that, would be the average velocity of a particle of air. At the ordinary temperature, — sixty degrees Fahrenheit, — the velocity would, of course, be greater.

Now, then, just let us consider how much we have established so far about these small particles, of which we find that the gas consists. We have so far been treating mainly of gases. We find that a gas, such as the air in this room, consists of small particles, which are separate, with spaces between them. They are, as a matter of fact, of two different types, oxygen and nitrogen. All the particles of oxygen contain the same structure, and the rates of internal vibration are the same for all these particles. It is also compounded of particles of nitrogen, which have different rates of internal vibration. We have shown that these particles are moving about constantly. We have shown that they impinge against, and interfere with, one another's motion, and we have shown that they come apart again. We have shown that in vessels of the same size, containing two different gases of the same pressure and temperature, there is the same number of those two different sorts of particles. We have shown also that the average velocity of these particles, in the air of this room, is about twenty miles a minute.

Now, there is one other point of very great interest, to which I want to call your attention. The word "atom," as you know, has a Greek origin; it means — that which is not divided. Various people have given it the meaning of that

which *cannot* be divided; but if there is anything which cannot be divided, we do not know it, because we know nothing about possibilities or impossibilities, only about what has, or has not, taken place. Let us, then, take the word in the sense in which it can be applied to a scientific investigation. An atom means something which is not divided *in certain cases that we are considering*. Now, these atoms I have been talking about may be called physical atoms, because they are not divided under those circumstances that are considered in physics. These atoms are not divided under the ordinary alteration of temperature and pressure of gas, and variation of heat; they are not, in general, divided by the application of electricity to the gas, unless the stream is very strong. But there is a science which deals with operations by which these atoms which we have been considering can be divided into two parts, and in which, therefore, they are no longer atoms. That science is chemistry. The chemist, therefore, will not consent to call these little particles that we are speaking of by the name of atoms, because he knows that there are certain processes to which he can subject them which will divide them into parts, and then they cease to be things which have not been divided. Now, I will give you an instance of that. The atoms of oxygen, which exist in enormous numbers in this room, consist of two portions, which are of exactly the same structure. Every molecule, as the chemist would call it, travelling in this room, is made up of two portions, which are exactly alike in their structure. It is a complicated structure; but that structure is double. It is like the human body — one side is like the other side. How do we know that? We know it in this way. Suppose that I take a vessel which is divided into two parts by a division which I can take away. One of these parts is twice as large as the other part, and will contain twice as much gas. Into that part which is twice as big as the other I put hydrogen; into the other I put oxygen. Suppose that one contains a quart, and the other a

pint; then I have a quart of hydrogen and a pint of oxygen in this vessel. Now, I will take away the division, so that they can permeate one another, and then, if the vessel is strong enough, I pass an electric spark through them. The result will be an explosion inside the vessel; it will not break, if it is strong enough, but the quart of hydrogen and the pint of oxygen will be converted into steam; they will combine together to form steam. If I choose to cool down that steam, until it is just as hot as the two gases were before I passed the electric spark through them, then I shall find that, at the same pressure, there will only be a quart of steam. Now, let us remember what it was that we established about two equal volumes of different gases at the same temperature and pressure. First of all, we had a quart of hydrogen, with a pint of oxygen. We know that that quart of hydrogen contains twice as many hydrogen molecules as the pint of oxygen contains of oxygen molecules. Let us take particular numbers. Suppose, instead of a quart or a pint, we take a smaller quantity, and say that there are one hundred hydrogen and fifty oxygen molecules. Well, after the cooling has taken place, I should find a volume of steam, which was equal to the volume of hydrogen, that is, I should find one hundred steam molecules. Now, these steam molecules are made up of hydrogen and oxygen molecules. I have got, therefore, one hundred things which are all exactly alike, made up of one hundred things and fifty things — one hundred hydrogen and fifty oxygen, making one hundred steam molecules. Now, since the one hundred steam molecules are exactly alike, we have those fifty oxygen molecules distributed over the whole of these steam molecules. Therefore, unless the oxygen contains something which is common to the hydrogen also, it is clear that each of those fifty molecules of oxygen must have been divided into two; because you cannot put fifty horses into one hundred stables, so that there shall be exactly the same amount of horse in each stable; but you can divide fifty *pairs* of horses among one

hundred stables. There we have the supposition that there is nothing common to the oxygen and hydrogen; that there is no structure that belongs to each of them. Now, that supposition is made by a great majority of chemists. Sir Benjamin Brodie, however, has made a supposition that there is a structure in hydrogen which is also common to certain other elements. He has himself, for particular reasons, restricted that supposition to the belief that hydrogen is contained, as a whole, in many of the other elements. Let us make that further supposition, and it will not alter our case at all. We have, then, one hundred hydrogen and fifty oxygen molecules; but there is something common to the two. Well, this something we will call X. Of this we have to make one hundred equal portions. Now, that cannot be the case unless that structure occurred twice as often in each molecule of oxygen as in each molecule of hydrogen. Consequently, whether the oxygen molecule contains something common to hydrogen or not, it is equally true that the oxygen molecule must contain the same thing repeated twice over; it must be divisible into two parts, which are exactly alike.

Similar reasoning applies to a great number of other elements; to all those which are said to have an even number of atomicities. But with regard to those which are said to have an odd number, although many of these also are supposed to be double, yet the evidence in favor of that supposition is of a different kind, and we must regard the supposition as still a theory, and not yet a demonstrated fact.

Now, I have spoken so far only of gases. I must, for one or two moments, refer to some calculations of Sir William Thompson, which are of exceeding interest, as showing us what is the proximity of the molecules in liquids and in solids. By four different modes of argument, derived from different parts of science, and pointing mainly to the same conclusion, he has shown that the distance between two molecules in a drop of water is such that there are between

five hundred millions and five thousand millions of them in an inch. He expresses that result in this way: That if you were to magnify a drop of water to the size of the earth, then the coarseness of the graining of it would be something between that of cricket-balls and small shot. Or, we may express it in this rather striking way: You know that the best microscopes can be made to magnify from six thousand to eight thousand times. A microscope which would magnify that result as much again would show the molecular structure of water.

There is another scientific theory analogous to this one, which leads us to hope that some time we shall know more about these molecules. You know that, since the time that we have known all about the motions of the solar system, people have speculated about the origin of it; and a theory started by Laplace, and worked out by other people, has, like the theory of luminiferous ether, been taken out of the rank of hypothesis into that of fact. We know the rough outlines of the history of the solar system, and there are hopes that, when we know the structure and properties of a molecule, what its internal motions are, and what are the parts and shape of it, somebody may be able to form a theory as to how that was built up, and what it was built out of. It is obvious that, until we know the shape and structure of it, nobody will be able to form such a theory. But we can look forward to the time when the structure and motions in the inside of a molecule will be so well known that some future Kant or Laplace will be able to form a hypothesis about the history and formation of matter.

25. The Circulation of the Waters on the Surface of the Earth.

BY H. W. DOVE.

WE live on the boundaries between two oceans; above the liquid expanse of the watery main, and at the bottom of the blue deeps of air. It is impossible for us to reach the surface of the latter, for our highest mountains pierce but its shallows, the azure waves rolling far over their summits. Of the former, only the surface is known to us; the secrets of its depths are hidden from our ken. Thus the greatest part of the firm crust of the earth is withdrawn from our investigation. Mighty masses of earth, it is true, rise up out of the ocean, making the proportion of the firm bottom of the sea of air to the liquid one as 51 to 146. But the idea that, could we succeed in draining the ocean dry, those masses that tower over the level of the ocean would serve to fill up the gaps, is long ago renounced as being incorrect. Humboldt fixed the mean height of the continents at about a thousand feet above the level of the ocean. While Bache calculated the mean depth of the Pacific at 14,190 feet, from the time needed by the wave of the earthquake (Dec. 23, 1859, when the Russian frigate Diana was lost), which rose thirty feet above the usual level, in the harbor of Simoda, in Japan, to cross the Pacific to San Francisco and San Diego, in California — rate = 6,1 league per minute, by 217 miles breadth of wave. Still this ratio is greatly exceeded in the deepest places; for Ross at a southern latitude of 15° 3', and a western longitude of 23° 14', found no bottom at a depth of 27,600 feet. Denham, in the Herald, found soundings in the South Atlantic Ocean, but at 46,000 feet, while Parker, in the Congress, and much about the same spot, failed to find

bottom at 50,000. Brooke let down a plumb-line measuring 42,240 feet in the Indian Ocean, a sea in which the ancient merchants used to point out a spot at the mouth of the Hoogly, in the Bay of Bengal, which they believed to be unfathomable, and therefore called "the bottomless pit." Let us, however, imagine our supposition carried into effect, viz., all the seas drained, all the rivers run dry, we should be very much at fault, were we to imagine we had now arrived at the region of rigidity, of freezing. For the heat which increases rapidly inwards, aids us in coming to the conclusion that, at a comparatively inconsiderable depth, that which on the surface is firm, will liquefy in the heat of the central fire; that the hard crust which surrounds this liquid heart does not bear the same proportion to it as the egg-shell does to the contents of the egg; nay, is so fragile that recently the opinion was expressed, this shell of earth was incapable of supporting such a mighty load as the Himalayas, and that this mountain range floated in the central liquid ocean like an iceberg in the waters. And no contemptible one, methinks, for this range towers five miles above the level of the external ocean. Judging by this, it is not hard to suppose that since even now the liquid so far exceeds the solid, the difference at an early period has been very much greater, perhaps indeed that the whole earth was once liquid.

The fundamental character of a fluid is the extreme mobility of its parts, which yield to every force that sets it in motion. If no external power, but their mutual attraction, operates on the fluid, the separate parts have nothing left to hold them together. They naturally assume the form of a globule, for the spheroid is that form which admits of the closest approach of all the several parts. If water falls, gravity can exercise no fashioning influence on it, as all the parts of a falling body move with equal rapidity; we here then perceive the spherical form at once assuming the figure of a drop.

This may be demonstrated in a still more striking manner

by pouring oil (which swims on the surface in water, but sinks in spirits of wine) first into alcohol, and then adding so much water till this mixture, of heavier water and lighter alcohol, attains the exact density of the oil. The oil then rolls itself into the form of a perfect ball or globe which floats about in the transparent mixture, as does our earth in space. Now, if a piece of wire, furnished at the lower end with a vertical metal plate, is thrust through the cork of the square glass vessel containing the mixture, it is easy to attract the globe of oil to this circular disk in such a manner as to cause it to completely encompass it. This done, turn the wire slowly round; the revolving of the inner-plate sets the oil in motion, which gradually assumes the spheroidal form; that is, it becomes flattened at the poles. Increase the rapidity of the motion, and the oil will detach itself and turn like a ring round its rotatory axis. As in the second experiment we behold, as it were, Saturn's rings forming under our eyes, so the first offers us the key to the riddle how the earth first assumed its spheroidal form, and how the ocean exhibits this form best, the irregularities of the land preventing it being so distinctly visible. Calculating our motions in reference to the centre of the earth, the nearer then we approach the equator, the farther we go from that centre; and, indeed, the mouth of the Mississippi is farther removed from the centre of the earth than its source. Those who delight in quaint expressions, can therefore say, if it so please them, that this mighty stream flows up-hill. But in order to judge of the fall of a river, its superficies must be fixed at every point of its geographical latitude according to its distance from the level of the ocean; that is, according to the position which its waters, along with those at its mouth, would take in a state of repose.

We have compared the earth to a falling drop. It is, however, less a comparison than the real fact, only in this case it is a drop falling towards the sun. I here employ the word "fall" in the same sense as Newton, viz., that gravity has

the same effect on the moving body as on the stationary. If, standing on a frozen lake, I fire a ball from a gun held scrupulously horizontal, and the same second, drop another out of my hand, they will both touch the surface of the ice at one and the same instant. Rapidly then, as the powder propels the ball, it still cannot escape the law of gravity: it falls exactly as the ball not acted on by the powder. The earth is such a ball hurled into space; and once set in motion, it would, but for the sun, fly straight on, only the sun will not suffer that. He compels the earth to deviate from her straight course, and to fall towards him. Thus, instead of a rectilinear path, she strikes into the circular one. All the effects of the forces, however, diminish with increased distance. That spot of the still liquid earth which is turned to the sun, falls farthest from the rectilinear point of contact, the centre less, and the side altogether averted, least of all. Thus both poles, diverging from the centre, impart to the liquid earth an elongated spheroidal form, its longer axis turned towards the sun. Such a change of form can naturally not take place in solid earth, as the closer adhesion of the parts necessarily prevent any displacement. All its parts, therefore, move in like manner as the centre-point, namely, all those *before* this same centre-point, hurrying it on in the same degree, as those behind drag it back. Now, our earth being neither all solid nor all liquid, the liquid water will form its spheroid on the unvarying solid globe, that is, it will accumulate at the two ends turned to and from the sun, and flow off from the sides to both places. If the earth did not revolve on her axis, then the ocean would once for all be deeper at the two former points, at the latter, shallower. But the earth revolving, the heavenly body which influences the flood, changes its position, before the spheroid he has been trying to form in the liquid covering of the earth has been completed. In this manner, a wave is produced which follows the heavenly body in its apparent course round the earth. The liquid spheroid then hangs over the solid globe

which revolves under it; each place in this way coming twice during the day, at noon and at midnight, to the spot of the deepening ocean, and twice, at six o'clock in the morning and in the evening, to the shallow spots. This phenomenon is known as ebb and flood.

Hitherto we have only taken the sun into consideration, and not mentioned that mute companion of our earth, the moon, to whom the earth takes the same place as the sun to us. The attraction, however, is mutual, the moon not only inclining to the earth, but likewise the earth to the moon; i. e., the former moves more rapidly when the latter stands on her path before her, more slowly when behind her; and she inclines sideways out of her path when the moon does the same. The same reasons which are at work to cause the sun to produce a flood, operate likewise on the moon, and with a similar effect. When all three bodies are standing in a straight line, as at full moon and new moon, the solar flood falls to the same spot as the flood caused by the moon; therefore the water rises here, for two reasons, higher than usual. When the three bodies form a right angle, which happens in the first and third quarter, at the same spot where the moon raises the tide, the sun causes an ebb, and we have therefore the difference of two effects. The former floods, known as the spring-tides, are considerably higher than the latter, to which we give the name of the neap-tides. But as the moon rises each day well nigh an hour later than the preceding, exact time fifty minutes — so if both tides meet to-day at noon, the lunar tide will set in to-morrow at one o'clock, while the solar tide unchanged will make at noon; the following day the former will take place at two o'clock, and so on. Thus in a week the lunar flood and solar ebb will happen together, while in a fortnight the flood will again set in as at the beginning of this term.

Now, we might believe, that the small near moon in the place where it hangs in the heavens has, by a hundred and sixty times, a weaker power than the big far-off sun, the lunar

tide would be comparatively less. And so it should, if the whole powers of attraction of the heavenly bodies were spent in the producing of the tides. But we have seen their power of producing tides is only the difference of their effects on the surface, and on the centre of the earth. The half of the earth's diameter nearer or more removed, is a much more considerable matter than with the sun; for the latter is distant from us 12,000 times the length of the earth's diameter, the former only thirty times. Hence a thirtieth of the lunar power is to the twelve thousandth part of the solar power, as 5 to 2 (more exact as 50 to 18). Wherefore the sea rises two feet under the influence of the sun, but five under that of the moon, for the difference between two small numbers can be much greater than that between two large ones. At the spring-tides the water rises 5+2, therefore seven feet; and at the neap-tides 5—2, that is, it rises three feet.

But what is the nature of the motion of the waters at their ebb and flow? Progressive or oscillating? The water of a river flows, that is, the following particles take the place of those gone before, as we can clearly see by any body floating on the surface. The case alters with the billowy ocean. A vessel does not float along on the crest of the wave; it rises on it, but then sinks down again into the watery-valley without any change of position. When the wind sweeps along a field of corn, every blade bends before the pressure to rise again afterwards. The wave that skims along the surface is formed by a continuity of blades; in the same manner the water rises and falls in succession at different places, and this succession appears to us like a lateral progress. The motion of the sea is exactly like that of the little wooden pegs in the inside of a piano, when we pass our hand rapidly over the keys. The undulatory motion of the sea is to the flowing stream what the transmission of sound is to the wind. It is easy to understand, therefore, why the tumultuous ocean can as little drive a mill-wheel, as a cannonade can set a wind-mill in motion. The wave and the sound are

vibratory motions, with this difference, that in the sound the atmospheric particles rather hold off from the second-producing body, and afterwards return to their places; while the water takes a perpendicular motion in the direction of the progressive wave. This latter motion, produced by a rising and falling, is hence termed a transverse or oblique vibration; the former, caused by a swaying backwards and forwards, a longitudinal vibration. What has just been said of the water, merely applies to those short chopping waves raised by the wind, the height of which is considerable as compared with the transverse section, and not of those tidal waves, which are very low in comparison with their immense cross section. In the latter, the perpendicular motion is not rectilinear, but the preponderating vertical direction accompanied by a little lateral push, which we detect in the shock of the beating wave. This produces an elliptical motion of the watery particles, the long axis of those ellipses being almost vertical, having only a slight inclination, and the short one horizontal. The tidal wave therefore, in its motion, more resembles that of the atmospheric particles, than the drops in a watery wave agitated by the wind. The oscillatory motion of the water at high tide may hence be termed progressive longitudinal, the height of the tide, which represents ebb and flood, being inconsiderable in comparison with the lateral motion.

Were the surface of the earth everywhere covered with an equally deep sea, a very broad double-wave would go round the earth from east to west within twenty-five hours, it being highest at the equator, and sloping quite away at the poles. Something resembling this is to be seen in the South Seas, where the land retreats almost wholly. The phenomenon, however, shows an essentially different aspect in the Pacific, Indian, and Atlantic Oceans. In each of those waters a new tidal wave always arises at the east coast, which is reflected on the west coast before a second primary wave has time to form. If you pass a violin-bow over the sounding-

board, the bow sweeping down calls forth on the margin of this elastic board inflections which progress over it like waves, and return reflected from the margin. The more equal the intervals are, which are set in motion by the bow, the more regular will be the meeting of the wavelets in their passage hither and thither; the progressive vibrations are soon changed into standing ones, when all the parts of the sounding-board vibrate simultaneously round their centre of gravity. Let us now compare the sun and moon, the bodies which influence our tides, with the light bow, and those vast ocean hollows or basins with the elastic sounding-board. Now, it is not improbable that a broad arm of the sea be made to oscillate like the water in a glass, when pushed rapidly backwards and forwards on a table, with your hand. Just as this oscillating water rises and falls most at the edges, and changes its position least in the centre, just so will the ebb and flood be stronger at the coasts than at an island in the middle of the sea. After having long asked how it would be with the ebb and flood in an ocean equally deep everywhere, and surrounding the whole earth, in the answer, of course only a theoretic one, a new step forwards has recently been made, by seeking to determine, by experimental observations, what aspect the phenomenon exhibits on the actual oceans of the earth. The result then has confirmed the fact, that the flood in America, indeed, comes from the east, but in Africa and Europe from the west. If the tidal wave enters a narrowing bay, it is heaved higher, but if it flows round a larger island, it may possibly be delayed so long on its way, as to come rolling in, when the other part of the wave is already on the turn. Just as on a sounding-board, when a water-mountain and a water-valley meet, there occur lines of rest. In the German Ocean there is a spot where the waves pressing through the Canal, meeting that branch of the great Atlantic tidal wave coming down from Scotland, completely absorbs the flood. The grandest accumulation is to be seen in America, in the Bay of Fundy, in

the rear of which there is sometimes a difference of a hundred feet in the level. If the Baltic had such a flood, Berlin would at certain times be a maritime town, for the pavement of Dorotheen Street, near the old Observatory, lies exactly a hundred feet above the zero of the water-mark in Swinemunde. But the Baltic is so perfectly enclosed by Denmark, that not till a few years ago did the Mecklenburgers succeed in proving that it *has* a flood, though, to be sure, but of a few inches. How grand, on the other hand, are the appearances on the west coasts of Europe! We can scarcely believe the testimony of our eyes, when we behold children in Ostend playing at the Digue on the dry strand, building their fortresses of sand, where but six hours later the bathers are disporting in the waters; or when from the cliffs at Bristol, at the ebb, you see a dog running through the stream at that place where the omnibuses are already stopping to pick up the passengers from the steamers; when on the line from Chester to Anglesea, the wide bay of the Dee is drained, where six hours later, returning from the Britannia Bridge, you see proud vessels afloat; or when at the ebb you can walk round Heligoland dryshod, where at high tide the surge breaks on the rocks with the din of thunder. The Scandinavian coast dips so abruptly into the sea, that its cross-valleys, filling with its waters, form the fiords. The water that the high tide has carried up, rushes back at low tide with such violence, that it has been said, though with much exaggeration, that Norway is a country where the ocean forms cataracts. If they are not cataracts, they are at least dangerous whirlpools, of which the Maelstrom is the best known.

And what is the final result of this ceaseless, restless tossing? The effect is the most visible in the polar sea, in the unceasing breaking up of the masses of ice, the enormous pressure of which the strongest vessels are often unable to withstand; the beneficial result, however, is that passages are opened up into territories which would otherwise be locked

in by an impenetrable wall of ice. The result of this thousand years' friction on our own coasts is likewise visible in our sandy sea-beach. If we try to calculate the value of the labor requisite to grind down solid blocks of rock to such minute grains, what company of shareholders would undertake to produce even the moderate quantity of sand on which Berlin is built? The reason of the great mechanical power lies herein: that the waves raised by the wind, being only superficial, penetrate but little below the surface, while the force which produces the flood acts on the whole body of water. A tidal wave which rises three feet at the equator, and slopes away regularly towards the poles, bears two hundred cubic miles of water from one quarter of the earth to the other, and in six hours. If this volume seems trifling to the aggregate body of water on the earth, which Herschel computed at the 1786th part of the bulk of the earth, still the force necessary to move such a volume over such a space is not despicable, when we remember that one cubic foot of water weighs sixty-six pounds. But how high must the tides have been when the whole earth was in a liquid state! If the first clods which solidified, united to form a connected crust, then the tides must have beat them more wildly together than now in the polar seas. Is it to be wondered at if there are everywhere traces to be found in the crystalline primitive rocks, of vast havoc and destruction, even there where they have not pushed their way into the shattered covering which holds the strata bound together? Such traces must be most distinctly visible in the equatorial regions, because there the vertical action of the heavenly bodies must have been much greater on the flood of a still quite liquid earth.

The knowledge whether the internal liquid ocean of fire is fluid, or whether moreover viscous, is hidden from us. Like the visible wave on the shore, perhaps it works its way, pushing and destroying at the firm crust, on which we can often clearly trace the marks of those progressive waves which we

call earthquakes. This crust is certainly plastic and pliable. Does not Sweden rise before our eyes out of the sea, which incessantly retreats from its coasts, while on the Pomeranian shores no such change is visible? In other places does not the land sink, as for instance in Istria, where Roman pavements are to be found below the present level of the ocean? Have we not through Darwin almost attained the certainty that the report of a sunk Atlantis is realized, in the main idea, in the Pacific Ocean; where the great Australian coral-reef, that no doubt once touched the coast, though now cut off from it by many a mile between, repeats the line of the coast in a great curve of some five hundred miles in extent, and where hundreds of coral rings — a lagoon in the middle — still mark out the expanse covered by the islands long ago ingulfed; while the corallines are laboring unweariedly on the yielding bottom, to keep up a connection with the surface of the ocean? Their activity will not come to an end, nor the whole colony become a dead rocky mass, till the bottom of the sea rises up high and dry, as so many of our mountain ranges, which, under the names of Mount Jura and the Rauhe Alp, stretch, like a wall of fortification, from the south-west frontier of Switzerland away into the region of Bayreuth.

Let us now pass from the attracting power of the sun and moon to another impetus or force which they possess, namely, their heat. And as we above designated the former power as immeasurably small with the planets, so now, in the latter case, we may omit all mention whatever of the moon, which, though it does not generate cold, as used to be thought, still its heat is so inconsiderable, that only very recently it has been positively proved to possess any. In treating this latter point, then, that of heat, the only body deserving of notice is the sun, whose heat is so great that in one year it could dissolve a crust of ice a hundred feet thick enveloping the whole earth. With every degree of heat, the water, the sea, too, on the surface, is changed into an aeriform invisible

body, which we call vapor, and which remains hidden from our view till it again returns condensed as fog, or a cloud. This evaporation increases with an increased extent of surface and a higher degree of heat; it is therefore greatest in the torrid zone. Incorporated with the air, the vapor ascending from thence towards the poles to the height of the atmosphere, becomes dense according to the degree of cooling, turning to rain, or snow, or dew, or hoar frost on the ground. To this process we apply the terms distillation and sublimation. As in the evaporation of water, it leaves behind it all the substances which it dissolved while in contact with its firm bottom, so rain water, being distilled water, is pure. If by an artificial extending of the superficies we increase the volume of evaporation, as they do in the south of France to gain the sea salt, we can closely inspect this uninterrupted chemical analysis. The atmosphere is then, as its name shows, a great steam apparatus, whose reservoir is the ocean, its furnace the sun, and whose condensing vessels are the higher geographical latitudes. If the rain falls immediately back into the sea again, it diminishes the pungency of the saline ingredients, which evaporation has intensified; and old sailors tell us that this is the case in the rainy season in so marked a degree, that in a calm, drinking water may be skimmed from the surface of the sea. For this reason the sea is less salt in the vicinity of the equator, in the region of calms, than in that of the rainless trade-winds; it diminishes again in the tropics, when the sinking trade-wind induces new falls, the so-called sub-tropic rains. But if, on the other hand, the rain falls on the land, if the soil is porous, it penetrates; or, should the soil be rocky, or clayey and impervious to water, it flows off to a lower lying level.

Now, the surface of the earth is composed of strata lying one upon the other, till down into the deepest depths; those on the plain are disposed horizontally, while on the other hand, those on the mountains take an inclined or sloping position. The gaping edges of those layers, the so-called

strata-heads, can be seen best on the summits of the mountains, as if, in the heaving of the great bulk, the outer covering of the strata had been disturbed, and the bursting mass had hardened into the form of the crystalline rocks. The water-tight and the porous strata alternating, the former fill with water when the rain falls on the exposed formations. The French have a good expression for such a spongy stratum, and call it *une nappe d'eau.* You can make the whole arrangement pretty clear to yourselves by a very simple contrivance. Take a pile of alternating sheets of dry writing paper, and well-soaked blotting paper, and then bend up the whole upper part of the book thus formed, out of its horizontal position. You thus gain not a bad idea of how the strata look at the top of a mountain.

Further, if you join two vessels at the bottom by a cross-pipe, and pour water into the one, the water in the other will rise as high as in the first, no matter how it may differ in size and in capacity, nor how long the pipe is. If you lead a pipe through a dike by the sea-shore, and curve it round, the water will rise to the sea-level, even though the pipe should end in a quill. Add one drop, and the whole ocean rises, naturally in proportion to its expanse. This is called the law of communication of tubes; of such tubes the U-shaped offers the simplest illustration. This law of course holds good for any number of vessels connected by tubes. Such are the Suterazi of the Turks, who, when they desire to conduct water from the one hill to the other, carry a pipe down the one hill, right across the valley, and up the ascent of the second. Had the Romans been acquainted with this principle, they would not have reared their splendidly arched aqueducts, which bear a more brilliant testimony to their feeling for art, than for their knowledge of physics.

The arrangement for providing all larger towns with water, is only an imitation of these Suterazi. A main reservoir is almost filled up with water, the connecting pipes branch off as required under the street pavement, and from

these the communicating pipes are conducted into the houses, and carried to a height which of course does not exceed the level of the main reservoir. The effort to rise is everywhere equal, and the upper wall of the horizontal part of the pipes, therefore, has to withstand a pressure from below upwards. If it cannot withstand the pressure, the water oozes out, and a source is formed. For, indeed, what else are those nappes d'eau but the water in those pipes, the walls of which are formed by the water-tight layers? Hence the springs ooze out at the foot of the mountains exactly where the upper covering has cracked, in making a bend round. But the spring is often to be found at a greater distance from the base, where, for example, the stratum comes to an end in the plain, or has been burst at some point. If the strata are disposed horizontally on either side of a so-called erosion valley, the water issuing thence can have no ascending power, unless the layers assume an inclined position at a greater distance. Those valleys lined with sloping layers fall into three divisions, viz., into concave or basin-shaped, in which the strata of both walls dip toward the valley; divergent valleys, where this is the case only on one side, which presents a succession of strata sloping gently downwards, and the other a steep descent laying bare the heads of the layers; and lastly, chasms, in which the heads of the strata are turned to both sides of the valley and slope off to the outside. From this it is to be expected that springs may be found on both sides in the basin-shaped valleys; in the divergent valleys only on the sloping side, and in the chasm not at all; as the rain falling on the heads of the strata would simply feed the springs of a neighboring valley. But Nature has frequently neglected to make the opening for the spring to bubble forth, and man must come to her aid, by breaking through the upper stratum with a ground auger, and in this manner get a well, an Artesian well, so-called from the province of Artois, where they were first introduced into Europe, in the year 1126. The ascending power of the

water naturally depends on how high the curve of the layer is filled with water. As long as the auger is boring in the upper stratum, it remains dry, but immediately fills with water as soon as the last wall is pierced, just like those pipes laid in our houses as a protection against fire, which, being left empty in winter to prevent freezing, fill instantly the obstruction is removed. If the nappe d'eau has no side bent upwards, i. e., if it is filled merely by lateral infiltration, then on reaching the water we get only a well, to obtain the water out of which, it has to be drawn, or pumped to the surface. If the spring has been bored in a high-lying region, it is possible the water does not rise to the surface at all, but remains at a certain depth corresponding to the point of issue of the stratum in the mountains. If the water-tight layer over the porous one were quite wanting, the water, if it possessed any force to ascend, would do so of itself. In this case it would be useless to add a new bore to the many already made.

The irrigation of the deeper-lying oases in Sahara seems from the most ancient times to have been effected by means of Artesian wells. Shaw says of Wad-reag, a collection of villages at the entrance of the Sahara, that these villages have no springs, the inhabitants procuring water in a peculiar manner. They dig wells a hundred or even two hundred fathoms deep, till they find under the sand a stone resembling slate, under which the water is found under the earth. This stone is not difficult to pierce, which on being done, the water bursts forth so suddenly, and in such abundance, that the men who have been let down frequently perish, though drawn up as quickly as possible. Olympiodor tells of the digging of such deep wells in the great oasis. They are called Bahr in the erosions of the lower plateau; on the plateau itself, Schreia.

When in the year 1854, after the battle at Meggarin, General Desvaux was encamped in the oasis Sidi Rasched, he remarked that on one side of it the palm trees looked poor

and shabby, while they were sound and flourishing on the other. On inquiring into the cause of this peculiar appearance, he was informed that there was a scarcity of water, the chief well having fallen in, and as they possessed no means of digging a new one, they were awaiting the day when their palms would cease to bear fruit, and they should all die of hunger. It was Allah's will. The general, on his own responsibility, concluded to send to France for a boring apparatus; an engineer from the house of Degousée, in Paris, was summoned. He found the matter practicable, and the following winter, after a division of Spahis had worked for four days, a spring bubbled forth out of the deserted shaft bringing 4300 litres of water a minute. The inhabitants rushed in crowds to the blessed spring, bathing their children in it. Now came petitions from all the other oases for similar favors, and since then some fifty wells have been brought into use without visibly diminishing the volume of water in those already dug. The love of exaggeration now prevalent has led many to express a hope that in the above manner the desert would, in course of time, be changed into a lovely garden.

The abundance of water in a spring may be exceedingly embarrassing. A considerable number of years ago, an Italian proprietor had an Artesian well dug in his grounds, but it proved to be so powerful, that it inundated his own and his neighbor's estates. All endeavors to stop the spring were unsuccessful; and the lawsuit for damages in which this involved him, completed his ruin. The story of Gœthe's Zauberlehrling was realized on him to his misfortune. Frequently the water-tight stratum runs away over the tops of the mountains and the heads of the porous layers, which are then prevented from filling with water. This was the case in Marseilles, where the fruitful soil of the vineyards was often entirely washed away by the thunder plumps. It struck the vintagers to bore deep holes through the upper stratum of clay, and to construct channels into which to carry the

rain water, and since that time springs about the circumference of a man's arm, which were unknown before, have formed at the harbor. In the year 1831 the fountain in the Cathedral Square, in Tours, cast up branches and shells from a depth of 335 feet.

Can we still doubt, in the face of those facts, that the water, which oozes forth in natural springs, is originally Tage-wasser (daylight water; the water which penetrates into a mine from the upper strata), as the miners call it. And who knows it better than they, they who keep up an unceasing struggle to get it under, who construct channels over the pits and mines in order to prevent it breaking in, by carrying it off rapidly; and who after a heavy shower of rain see it appear first in the lower, and afterwards in the lowest depths. How many sources dry up after long drought, many so frequently as to get the name of "hunger-springs," by way of contrast with those in Switzerland in spring, and which on the first dissolving of the snow burst forth everywhere. And yet there are still to be found adherents of the so-called capillary system. We know it is true, that in a narrow tube the water with a curved concave surface stands higher than in a wide vessel into which the tubes are introduced; but the water can be higher only as long as the surface is hollow; if it has run out, the surface must first be equalized; that, however, can never be, because then the condition of standing higher no longer exists. You see in dipping a bit of sugar into your coffee, it imbibes the coffee, but no coffee spring will ever bubble forth out of it.

But we are told that, in the hot summer of 1822, the water collected in unusual quantities at the bottom of the mines in the Harz Forest, while on the surface all the springs ran dry. How easy it was to explain this by saying, that, the earth loosened and cracked by the heightened temperature, its natural capillary tubes were so much widened that they could no longer raise the water to the

surface; hence it was compelled to collect at the bottom! This explanation is certainly simple, but simpler still the following: That as those waters were raised by means of mill works driven by springs, on the drying up of those springs, the works stood still and could not raise the waters!

As frequently several strata containing water lie one above the other — in digging for coals in St. Nicholas d'Allierment, near Dieppe, seven with considerable ascending force were discovered, the last a thousand feet below the level, if the upper one does not yield water enough, the borer is sent down deeper, though not always with a happy result. It has happened thrice in Würtemberg that the water thus obtained disappeared, for instead of a new layer, a cavity had been pierced, into which the water disappeared.

As a rule, the water in the stratum thus pierced is stagnant, but sometimes also flowing, in which case the plummet drops suddenly deeper, and begins to swing hither and thither, as in Paris at the Barrière of Fontainebleau, where it fell twenty-three feet. At the Gare Sain Ouen, of five springs bored, the third had so strong a flow that the stones which the borer had brought up out of the deeper shaft were carried away; this obviated the necessity of expediting them up to the top opening; they were raised no higher than to the third. How do such subterranean rivers originate? This may be observed in the Carse, in Carniola. There a younger, firmer limestone formation lies on the top of another quick-crumbling one. If the substrata is destroyed, the upper sheath falls in. In hundreds of examples cavities formed in this manner are to be seen on the line of the railway between Vienna and Trieste. If a river falls into such an opening, it disappears; re-appearing again afterwards at a great distance. Inquiring my way at the nearest post-house to the Perte du Rhône, the official said to me, "You don't need to go there; you see something much more remarkable in the garden at the back of my house." And indeed the sight was worth looking at. I found myself

suddenly at the side of a perpendicular, deep-cut, perfectly dry channel, the rocky bottom of which was perforated like a sponge. Now, when the water of the subterranean river rises, it oozes out of these apertures, filling the whole bed. And did not Livingstone see the mighty waterfall of the Zambesi disappear into a deep cleft? Something similar has likewise been observed in plains, as, for instance, in the case of the Guadiana, which for a time is lost in a great meadow, so that, when the Spaniards are told of the great bridges in England, they answer proudly, in Estremadura there is one on which a hundred thousand oxen can graze together. Sometimes those subterranean rivers only flow periodically, the explanation of which phenomenon is to be found in Greece.

The south of Europe shares the subtropical rains which fall heaviest in autumn, continue throughout the winter on to spring, when they reach a second maximum, while in summer there fall none. In the Morea, a part of those waters flow from the mountain steeps right into the sea; the others collect, forming a lake in the deep ravines of the interior. The side walls of these ravines are cracked and rifted, and form natural drain-pipes to the lakes, which are called Katavothra, when in the rainy season the level of the lake rises to or above the mouth. The issues of these canals are called Kephalovrysi, i. e., river-heads. In this manner the waters of the lake of Stymphalos form the Erasinas; those of the plain of Argos, at Mantinea, the Anavolo; those of lake Phenia, the sources of the Ladon. Drama Aly, the last Bey of Corinth, in order to prevent the stopping up of those issues, had an iron grating put over three of them at the lake of Phenia. At the outbreak of the Greek war of liberty they were removed, and a rich plain was thereby turned into a lake of 150 feet deep, and 20,000 of mean breadth. It is almost the same case with the lake of Copaiva, in Bœotia, between Helicon, Chlomo, and Ptoon. At the end of the summer, in August, this lake was trans-

formed into a plain, with the exception of a little pond at Topolia. By here widening the Katavothra, man had aided Nature ; nay, in antiquity two artificial tributaries had already been contrived. If these subterranean canals open into the sea, sweet-water springs are originated, as in Anavolo, Artros, and many other points of the rugged coast of Argolis, Laconia, and Achaia. Such places in the days of antiquity were regarded as sacred spots, whence the ruins of temples are so often to be found in their vicinity. But as a proof of how far those water-tight strata can run out into the sea, an English convoy-ship came upon a vast sweet-water spring, bubbling up at a distance of a hundred nautical miles from the nearest point of the Indian coast. This can never occur in the shattered primitive rocks, which lie everywhere scattered about. Therefore in a granite vale, we find many, but only small springs, which, hidden away under the stones, betray their presence by their murmuring. What a contrast between such springs and those of the Vauclose, which in one minute, even when their flow is scantiest, yield 1200 cubic feet of water, and threefold the quantity at other times.

Those springs which originate in glaciers form a class by themselves. They are born of the water melting from the surface of the glacier, penetrate between the rifts, then flow on under the ice, till at last they issue forth, very frequently out of a splendid ice-grotto, The finest instance of this is the source of the Ganges, which breaks out as a stream of one hundred and twenty feet broad, from a perpendicular wall of ice in the vicinity of the temple of Gangatri. All those glacier rivulets known by their white soapy-looking water, have a fuller flow during the day than at night; and the higher the temperature of the air, the more abundant are their waters. We have one remarkable proof of their flowing under the glacier-ice. In the year 1790, Christian Borer, the landlord of the Grindelwald, tumbled into one of those rifts in the ice, while driving his flock down from Bœniseck.

When he came to himself, he discovered he was lying in flowing water, and began to make the best of his way out again with his broken arm, coming to light at the gate of Lütschine, having crept for hours through icy flowing water.

The fruitful soil of our lowlands generally lies on a subsoil of sand, and is protected by dams from the inundations of the river. If, on the breaking up of the ice, the water rises considerably, the inhabitants seek to stem the tide by raising the dike; but the combined exertions of the inhabitants of the villages are often not sufficient to avert the danger by reason of another circumstance. The embankment thrown up, itself composed of firm soil and girded with solid wickerwork, would be quite able to resist the lateral pressure of the rising waters; not so the sand-stratum, however, on which it is erected. While all are busied on the top raising it, then suddenly there bursts out behind it a well-ground; that is, the ground is covered with springs that bubble up with increasing force, bringing quantities of sand with them; the undermined embankment falls in with an awful crash, and the lowlands are covered with water. It is an incorrect conception of the matter to say the sand, which after such a catastrophe covers the fruitful soil, is the sand from the river. We should much rather say, that in the turmoil of waters the fruitful top-layer is carried away, laying bare the sandy sub-soil. The white stripes, therefore, like the foot-path on a meadow, lie deeper than the green sward. Berlin has unfortunately well-ground; accordingly when the Spree is at high water the cellars are filled. Von Oesfeld has published a chart of the most considerable of those inundations.

The difference between the coldest and the warmest month in the year, for the surface of the ground in Berlin, amounts to 13.64 degrees; at one foot below the surface, to 12.95; at two feet, to 10.69; at three feet, to 9.14; at four, to 8.51, and at five, to 7.95. According to this rapid decrease, we can calculate that at a depth of twenty-four feet below the

surface, there will be but half a degree of heat, and at from sixty to seventy feet, there will be scarcely any traces of it left. The so-called variable stratum has according to this not even 100′ of power. Springs show, therefore, that the deeper the horizontal part of the nappe d'eau is imbedded in this variable stratum, the more equal is its heat. Thus it comes that adjacent springs often differ considerably in this respect. At Marienberg, near Boppard, Hallmann's minute and careful observations have proved a yearly difference in the heat of the atmosphere of 15.72 degrees; at Michael's Spring, of 7.73; at Hassborn 4.77; at Mühlthalquelle 2.99; the Hirschkoppquelle 2.62; the Salzbrunnen 2.14, and at the Louisenquelle 0.96; while the chief source (Quelle), that one which feeds the whole bathing establishment, the Orgelborn, only of 30.54 degrees. And this variability is not simply observable in mountain springs, but also in those of the plain. In Conitz, after many years' observation, the difference between the coldest and warmest month amounted in one spring to 3.06, in another to only 0.46, while the atmosphere showed 17.22 degrees of heat. The Gesundbrunnen, in the Oranienburg suburb of Berlin, varies only $\frac{3}{10}$ of a degree within a year. The skater is, therefore, not a little astonished when he finds the same spot in the pond bubbling up through the ice, that in summer, while bathing, he had avoided on account of the cold. In the torrid zone, where the heat is equal throughout the year, and the difference between day and night greater than between summer and winter, the above is an every-day appearance. Lucretius, for instance, tells of a source near the temple of Jupiter Ammon, in the oasis, which was colder in the day, and warmer at night. The earth, adds he, is like a folded hand; in the cold it doubles itself up to prevent the internal warmth from streaming forth; in external heat it opens, and the earth cools because the internal warmth escapes. What a graceful explanation this is! It is a pity, however, that it is perfectly false, for the thermometer shows us that what is here

explained, viz., the variation in the temperature of a spring does not exist at all.

The best spring in the tropics can afford little refreshment, as the mean differs but little from the heat in the hottest months. While with us everything grows fresher and stronger around them, in Lapland and Iceland they are a curse for vegetation by bringing their icy cold into the short, hot summer. A source in Cumana = + 20°, differs from the hottest month = 23.3, only about 3.3; in Cairo about 5.9; in Strasbourg 7°; in Upsala about 8.3. But even here Nature avoids the extremes permitted her, for while in Basle the temperature of the springs is equal to the mean heat of the atmosphere, in the tropical regions they are below the mean, while in the frigid zone they exceed the temperature of the ground by several degrees. It is hardly necessary to add, that the rainy season, above all other causes, exercises an influence on those varying conditions. But even supposing an equal division of the quantum of rain within the annual period, there are manifold reasons for the temperature of the springs being higher, in higher degrees of latitude, than the atmosphere. In the severe cold of winter, for instance, the water is prevented penetrating the frozen ground till a thaw sets in; in other words, till the degree of warmth is higher. Hence the mean heat of the water which feeds the springs must of necessity be higher than the mean heat of the atmosphere. If we penetrate through the variable stratum deeper into the ground, the degree of heat, it is true, remains unchanged throughout the whole year, but rises the deeper we go. While our springs on the surface have 8° of heat, the water in the bore at Rüdersdorff, 700 feet below the level of the Baltic, has 18.2; in the bore at Rehme, near the Porta Westphalica, 2144 feet deep, 18.5; and on boring the well of Grenelle, in Paris, it rose from eight degrees and a half to 22.2, when at a depth of 1683 feet, at length penetrating the chalk-bed and reaching the greensand, which slopes off at Tours, they came upon a

water-bed, the ascending power of which was so great, that in Grenelle, people used to climb up a high mast in order to see, at the top of it, the water flowing out in the shape of a shell.

There is, therefore, no difficulty in understanding the origin of hot springs, both as concerns the height of their temperature, and their variability, which a comparison between the observations of Carrère in the year 1764, and those of Anglada in 1819, clearly proves, though at first Anglada fancied the results he had obtained were opposed to those of Carrère, not having remarked the thermometer the latter had used was divided differently from his own. In Mont Dore people now bathe in a hot spring with 30.7 degrees of heat; this same spring was used in the days of Julius Cæsar without its first undergoing a cooling process. Now, as one can stand the hot bath at Roussillon (40°) for only three minutes, and in water of 36° about eight minutes, the springs must have retained their degrees of heat since the days of the Romans, unless, indeed, they all had skins like the Turk whom Marshal Marmont saw tarrying for a long time in a bath with 60° degrees. It no longer strikes us as extraordinary, that the hot springs appear just where the cuttings in the primitive rocks are deepest; or that their temperature generally rises the nearer we come to the granite-axis of the mountain; as there, that which once formed the interior having been forced to the surface, the deeper the water can penetrate, the more probable it appears. Thus it becomes clear that, while the springs in Roussillon, at Olette, show 70°, those of Dax, in Foix, only 60° of heat; those of Bagnères de Luchon, farther west, 50°, those of Barèges 40°, the eaux bonnes, and les eaux chaudes, in the valley of Ossan, 30°, and lastly, those of Cambo, not far from Bayonne, and farthest from the chief mass of granite in the Pyrenees, only seventeen degrees. That the hot mineral waters owe their heat to their springing from a great depth, is corroborated by the chance discovery of a spring with forty degrees of

heat, in a copper mine, 1350 feet deep, at Wheal-Cliffort, near Redruth, in Cornwall, the temperature of which almost entirely agrees with that of the Bath-wells.

It is no contradiction to the above, to say that springs sometimes change their degrees of temperature considerably in consequence of earthquakes, for by such displacement of the rocks, their connection with deeper-lying strata may either be cut off, or opened up. After the great earthquake at Lisbon in 1755, the Source de la Reine in the springs of Bagnères de Luchon, rose forty degrees, thus being transformed from a cold, into a hot spring, while the reverse took place in a spring in Bagnères of Vigorre, in consequence of a great earthquake in the year 1660. When on September 29, 1759, the Jorullo, in the municipality of Valladolid, rose at a distance of thirty-six miles from the coast, and forty-two from any other active volcano, the rivers Cuitimba and San Pedro, near the Cerro de St. Ines, were lost. Their clear waters had once irrigated the sugar-cane fields of the adjacent Hacienda. At a distance of six hundred feet off, there broke out in their place two rivers from the clay-vault of the Hornitos, in whose waters Humboldt saw the thermometer rise to forty-two degrees.

On its long subterranean path, the water generally comes in contact with substances which it has power to melt. Even common spring-water is, for this reason, not so chemically pure as rain-water; and although it holds but a very small quantity of carbonate of lime in solution, it is still sufficient to form, in conjunction with soap, a flaky lime-soap, while in rain and river water the soap dissolves equally; and it prevents pease and beans becoming soft in boiling, for the lime adheres to the shells, and in this manner excludes the entrance of the water. Therefore we call spring water hard, in contrast with the soft river water. A spring becomes a mineral spring, when the ingredients which it hold in solution, exist in greater quantities.

Pliny has given us the key, so to say, to the fabrication of

mineral springs; it is as follows: The waters partake of the nature of the country through which they flow. Starting from this dictum, Struve investigated the basalts, phonolite, and porphyry in the vicinity of Bilin, Teplitz, Marienbad, Carlsbad, and Eger. After having discovered all the solid ingredients of the neighboring chalybeate springs, he proceeded to imitate them artificially, by bringing the pounded rocks in contact with carbonic acid gas and water, under the pressure of a pump. The brilliant results of these experiments are the artificial mineral waters, a blessing indeed more especially for those regions remote from the healing springs. Those waters have been objected to on the score, that in the natural waters, there were possibly unknown ingredients, an assertion which has been confirmed since the discovery of Cæsium and Rubidium in the waters of Baden-Baden and Türkheim, by means of Bunsen's spectral analysis. But further, you have to consider that, along with the healing substances beneficial for a certain form of disease, the natural mineral waters frequently contain such as promote indigestion, to omit which is surely better than to fabricate a slavish imitation. The assertion that hot mineral waters, in cooling, follow other laws than artificially heated waters, is a fiction, probably devised to throw discredit on the artificial mineral waters.

If from the point of view of science, I mean to ascribe the same effect to the artificial waters as to the natural, still it is by no means said, that a course of waters taken at home have the same beneficial effect as when drank on the spot. One invalid amongst the healthy is always isolated; he is merely endured. How different in a watering-place, where everybody is sick! where you may see plainly written in the face of every visitor he belongs to the majority, looking like a parliamentary deputy who, seeing his party has the upper hand, has laid aside the resigned opposition air, which but a short while ago, so strangely contrasted with the aplomb which so peculiarly marks out the props of govern-

ment from among the other creatures of this earth. Added to all that, there is the prescribed diet, which, it being in the interest of the landlord, is much more strictly adhered to, than at home; and lastly, the infinite healing power in *idling;* not alone for those who at home are overwhelmed with business, but also for those who are accustomed to it, because, for once at least, their hearts are filled with a proud satisfaction in the fulfilment of their duty! In short, every one comes out in a new character. You meet bankers who, in the reading-room, are more eager to have a first peep of the lists of new comers, than of the exchange list; lawyers, who for once all agreed on some case submitted to them; councillors, who have laid aside the severe official air which might lead us to suppose, that there was some real reason for the mysterious expression of their countenances; military men, disguised in the apparel of ordinary human beings; and by way of contrast, people putting on a negative incognito, being nothing, and wanting to make you believe they are something. What invalid would not recover under those circumstances, when disease itself assumes a graceful form; for how often do you see faces which suggest the wondering question, what can be the matter with him or her! If such then is the case even in a small watering-place, what a superabundance of attractions does not a large one offer! This confusion of tongues, this wondrous mixture of bonne société and demi-monde, both brilliant and still so different; like a jewel and its imitation! What fine shades in the mutual bow and in the manner of conversation; from the highest grade, when questions are addressed but no replies waited for, to the very lowest step of going thoroughly into a matter. And now, when you step out of those gayly decorated, fairy-like halls, into one of those sequestered vales, and you cast yourself down near the source that babbles on heedless of listeners, you behold below, a brook meandering through the fresh meadow, near by, a mill high above, a castle clothed with ivy, and overlooking the dark-

green of the woods, can any one be surprised, that in the marriage contract of a Parisian lady the words, " et la saison à Bade," dare not be omitted.

Of all the mineral springs, the saline are of the most importance. The theory of lixiviation has been most clearly and satisfactorily proved on them; science having succeeded in directly tracing the birthplace of their saline ingredients, to the enormous beds of rock-salt. This important discovery, to which Prussia owes Wilitschka, in Stassfurt, was made by Herrn von Langsdorf, who with unwearied perseverance carried on his boring operations in Wimpfen, in Würtemberg, from August, 1812, on to the spring of the year 1816, till, at a depth of 475 feet, he at length reached a bed of rock-salt sixty feet in thickness. This success provoked imitation in North and South Germany, and in France.

The carbonate of lime which so many springs hold in solution, leaves a firm deposit on the evaporation of the water. This evaporation produces, in the limestone caves, those wonderful stalactic formations we are all acquainted with. Just as icicles are formed in thaw-weather, so do limestone drops form on the roofs of those caves, from the calcareous sediment left after evaporation. Those pendent formations are met by others rising from the ground, produced by the falling drops, till both meet in the shape of a sand-glass, but which the continual accumulation changes in time into fine slender columns. A more rapid evaporation takes place at one waterfall, the Lapis Tiburtinus of the ancients, now generally known in another form, as the Confetti di Tivoli.

The Carlsbad sprudelschale (thermal tuff) is a well-known example of the stalactites of hot springs, every visitor bringing away with him at least one petrified souvenir. Here, too, this deposit is a result of increased evaporation from the falling of the water. A fine instance is the Pambuk Kaleffi (the cotton-castle), so-called from the picturesque shapes of the calcareous deposit — the Hierapolis of the

ancients, of which Strabo tells us its waters solidified so rapidly that canals were transformed into walls made of one solid piece. These springs take their rise in large numbers in a table-land; now, as they themselves cast up ever new obstacles, they have to make their way in devious channels, till reaching a steep of three hundred feet, they fall over it for a reach of about half a mile. According to Tchichatschef, the enchantment of the scene — the vista of stalactites, half dazzling white, half yellowish, which cover the wall, beggars description. Something similar may be seen in the province of Auckland, in New Zealand — in the Tetarata, on the north-east coast of the Roto mahana. The hot bubbling water flows out of a snow-white basin covered with stalactites, eighty feet long and sixty broad, over self-formed terraces, hewn, as if out of dazzling marble, into a series of deep blue basins, such as the most refined luxury could not have devised better; from their gradual descent, a gradation of temperature takes place; and they are large enough for a man to swim about in comfortably.

It is therefore no fable, when the Greeks speak of bridge-building springs. Tchichatschef has made a very fine drawing of the one in Pambuk Kaleffi which, spanning the dry bed of the river, affords the traveller resting beneath, an agreeable coolness from the evaporation of the dropping water. On the way from Erzerum to Trapezunt, Ely Smith saw another. In this one the crust of the tufa had grown too heavy, broke, and having fallen into the river, formed the pillar across to which this natural bridge is thrown. On the way from Algiers to Constantine, you meet with springs whose bubbling noise and rising columns of vapor are to be seen and heard from a great distance. An innumerable quantity of dazzlingly white calcareous pyramids here assume the oddest rocky shapes. The Arabians tell about them, how a mighty chief had wedded against the laws of the Koran, and Allah, wroth with the Marabut who married them, transformed the bridal pair and all the marriage guests

into stone; and the wicked boiler that contained the marriage feast was condemned forever to boil and bubble. Hence the name Hamman el Meskhatin, the Cursed Springs.

Frequently the stalactites rise gradually tube-like, ending in a wide basin. The hot water running into this basin has naturally a much higher temperature at the foot of this tube, than at its surface; the vapor-bubbles which form beneath having to bear not only the pressure of the atmosphere, but the pressure besides of the column of water above them. Those above approach the boiling point; but those waters, which from their cooling on the surface cannot reach that point, suddenly boil up, when brought by a stronger swell into chance contact with larger bubbles, sending up the water mixed with steam, with an enormous force, to a great height. The best known of such hot springs are the Geysers, and the Strokker, in Iceland. The temperature of the water of the former, at the bottom of a shaft of fifty-nine feet deep, and nine broad, is a hundred degrees; hence twenty degrees warmer than the usual boiling point; the temperature of the latter, ninety-two degrees at a depth of twenty-seven feet in the tunnel, which reaches forty feet down.

The usual height to which the projectile force of the latter carries the water, is one hundred and fifty feet, but on the removal of a possible obstruction at the lower opening, it may rise to one hundred and eighty.

The New Zealanders say of the Tetarata, that sometimes the whole body of water is hurled out of the principal basin with an awful force; on these occasions one may look down thirty feet into the empty basin, which, however, rapidly refills.

The crustaceous deposits of cold springs correspond to the thornstone of our drying houses, while the incrustations of hot springs may find their analogy in the sediment which overlays our steam engines, the removal of which remains a still unsolved problem.

The vastest mineral spring is the sea itself. But the

balance in which its component parts are held, chiefly effected through evaporation, influx, and other organic processes, can only then be understood, when we shall have traced the farther course of those waters which are, so to say, born of the springs, namely, brooks, streams and rivers, — over the surface of the earth, the study of which would form a second part to our present train of reflections, and would be the immediate visible supplement to that Circulation of the Waters, the first processes of which, from their taking place in the regions of the air, and under the ground, hence removed from our sight, have been so long misunderstood.

26. What is Actinism?

ACTINISM is the chemical power which is necessary to excite germination in plants. It emanates from the blue ray of the spectrum, and is the same power which operates on the sensitive silver in photography; photography being, by the way, an entire misnomer, since the pictures are drawn by the actinic power, and not by the luminous ray. Nay, more, the blue, the luminous ray, is, like the red, a positive hinderance to the working of the actinic power. It is most difficult to obtain good photographic results under the bright sun of the tropics. Moreover, if a spectrum be thrown on a prepared photographic surface, there will be two points only where the paper is preserved positively white — viz., the points on which the red and the yellow rays are respectively collected in the spectrum. Neither will seeds germinate so long as they are exposed to bright light. Again, by another experiment, it can be satisfactorily proved that the trail in the blue ray alone renders that power which is the sole agent in photography; for if we exclude the blue rays by passing all the light admitted through a yellow glass, the most sensitive photographic material may be exposed to

the strongest sunshine without undergoing any change whatever.

The result of experiment is, that germination is excited by the actinic power of the blue ray; the formation of leaf and wood by the luminous power of the yellow ray; and the development of flower and fruit by the heat of the red ray. How the actinic ray reaches the seed in the ground is hard to understand; but that it does penetrate where the luminous ray is unable to reach is plain from experiments, which go also to show that the exclusion of the luminous ray is necessary for the operation of the actinic. Shade is always, absolute darkness sometimes, necessary for the success of the germinating process. Plant cress-seed an inch deep in three plots; over the first place a blue, over the second a yellow, and over the third a red glass. The seeds under the blue glass will be up days before those under the red; and of those under the red a few only will germinate. Those under the yellow will not germinate at all. It is found that those seeds which come up under a white glass, in from eight to fourteen days, will, under a blue glass, be up in from two to five days; that where thirty per cent. of seeds came up before, sixty per cent. can now be raised; and that some seeds from tropical countries, which could not formerly be raised in this climate under a white frame, will germinate freely under a blue one. It would seem that the depth to which the air can penetrate the soil is the measure of the depth of germination. This is the practical result. There appears to be no limit to the duration of the dormant vitality of seeds, so long as they are preserved from chemical change. The mummy wheat sprang up again, under the actinic ray, after it had been sealed from the air for nearly three thousand years. The seeds in the coal measures have, unfortunately, undergone great chemical changes; otherwise there would be no reason why we should despair of seeing the indigenous palm groves of this land flourishing once more.— *Poetry of Science.*